STARs

STARs Evaluation Tool User Guide

Deliverable 5

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1 Introduction

ERA-NET ROAD II (ENR2) is a Coordination Action comissioned by the 7th Framework Programme of the EC (www.eranetroad.org). Within the framework of ENR2 this joint research project was initiated as an answer to the call “Design – Rapid and Durable Maintenance Methods and Techniques” issued within a cross-border funded, trans-national joint research programme. The funding National Road Administrations (NRA) in this joint research project are Belgium (Flanders), Germany, Denmark, Finland, Netherlands, Norway, Sweden, Slovenia and United Kingdom.

The aim of the STARs project was to develop a methodology to score road works schemes on three interdependent aspects which are normally considered in isolation: road user safety, road worker safety and network performance. This will encourage national road authorities and their suppliers to take a holistic approach to managing safety risk and network performance and facilitate more comprehensive ranking of alternative management strategies.

To achieve this objective, three risk equations for performance at roadworks have been developed and included in the STARs Roadworks Evaluation Tool, together with a Multicriteria Solver Module transforming the individual and absolute scores into a “STARs” scale. This scale will be used to produce an unbiased rating of individual management strategies.

This document guides the user in assessing road works schemes with the STARs Road Works Evaluation Tool. It briefly describes its working structure, lists the project parameters to be used and guides the user step-by-step using screenshots and case studies. The methodology being used to develop the tool, details of the technical concepts underlying the three equations / models and are described in Project Deliverable 4 – STARs Final Report.

This tool is intended for use by road works contracting authorities in setting performance targets for road works schemes, contractors in achieving these performance targets and road authorities in planning and assessing proposed road work schemes. It can be used to assess real, proposed or hypothetical road works schemes in terms of the safety of road workers and road users and the network performance, but also to assess the impact of varying management strategies in order to minimise the risk in all three areas at the same time. Alternative strategies are ranked to identify the optimal solution.

This tool is proof-of-concept only and as such has limitations, for example it is designed for roadworks on motorways and for planned works only, i.e. not reactive incident management. It should also be noted that the tool is intended primarily for comparison of different management strategies for a given roadworks. Care must be taken if the use is to compare fundamentally different roadworks since (for example) works with a longer duration will pose a larger risk to all three areas, however this does not necessarily represent a poor management strategy. It is also designed for use across European countries and as such, a user may find that options are available that are contrary to their country’s legislation or current best practice; it is expected that the user should only select options that are appropriate. The tool can currently be customised for use in a single country if required; a possible future development of this tool could allow the user to select the country and the tool would automatically adapt as appropriate.

2 Tool description

Figure 1 shows the working structure for the STARs Road Works Evaluation Tool; it is structured around the three following modules: Road works project, Evaluation tool and Multicriteria solver module.

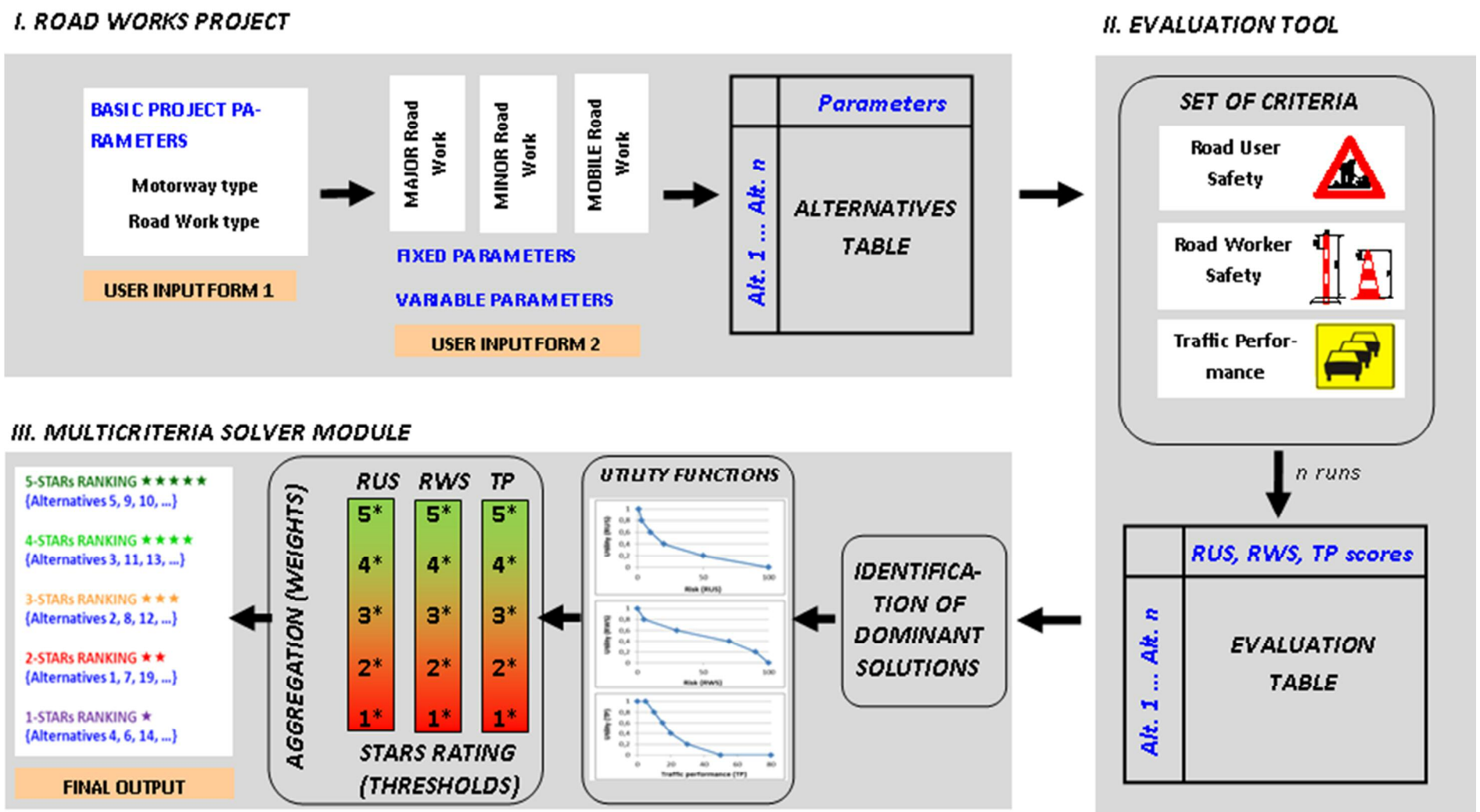


Figure 1: Working scheme of the STARs evaluation tool

Module I. Road Works Project

This module is the user input module where the user describes the project, i.e. the road work scheme to be evaluated. Basically, data about the infrastructure, the road works, the layout and operational parameters must be provided. For each of the three road work types considered in the following table (for full details see STARs – Deliverable 1), a list of relevant parameters has been identified. The combination of these parameters (some fixed, some variable), will generate the 'Alternatives' of the problem (i.e. all the parameter combinations of the road work scheme(s) to be evaluated).

Type:	**Definition**
Mobile	Mobile and intermittent road works of limited duration carried out using, for example, vehicles and / or mobile devices (such as TMA / LMCC) to create a safe working environment for short-term access to specific sections of the road.
Minor	Stationary (i.e. not mobile) road works that can only be carried out where conditions meet defined criteria in the appropriate national guidance. Definitions may be given in terms of traffic flow, visibility and/or the duration of the work.
Major	Road works that are in place for long periods, where workers may be behind an approved safety barrier and / or different equipment, layouts or techniques are used to manage traffic and safety compared to minor works.

Table 1: Definition of road works type

The parameters are classified following two main categories:

- The **Fixed parameters** are site, country and layout specific or operational parameters the project manager decides to fix. This means only one specific value is taken by the parameter. Two options are possible in this case:
    - o User input (number): number value given by the user;
    - o User input (tick box): the user is asked to tick a specific value in a tick list

  Typical fixed parameters are motorway and road works types, length of whole works, traffic flow, number of lanes closed, time taken for works, length for advance warning, TM vehicle conspicuity standards, etc.
- The **Variable parameters** are operational parameters the user chooses to vary. For parameters identified as being variable, the user can further select two or more values in a tick list to assess the impact of that variation in the road work scheme.

  Typical variable parameters are speed compliance management, delineation, width of open lane, lateral distance between workzone and traffic, etc.

Some parameters are fixed in the STARs evaluation tool; others can be selected as *fixed* or *variable* by the user. The legislative, strategic and operational issues specific to the country as well as the local constraints will of course highly influence the user's choice.

Values attributed to fixed and variable parameters together populate the '**Alternatives table'**: a matrix defined by modifying the variable parameters one by one and in which each alternative is described by the values associated to each parameter.

Module II. Evaluation Tool

The second module is the core of the evaluation tool. It groups the three **evaluation criteria**; i.e. the three risk equations designed to assess the performance of the alternatives pertaining to the three risk areas; i.e. road user safety, road worker safety and network performance. Each equation works independently but all three use the same set of parameters and feed, after n runs of the evaluation tool (n being the number of alternatives to assess), the **Evaluation Table**.

As further described in the Deliverable 4 – Final Report, these criteria have been developed using state of the art literature and partners knowledge. An initial calibration has also been realised.

Essentially, the Evaluation table is the former Alternative table updated with the absolute (i.e. non-standardised) scores for each alternative from the three criteria (see Table 2). The next immediate step is first to select the "dominant" alternatives (i.e. the "best candidates" solutions) and second to transform the scores into comparable scales (e.g. normalised values ranging from 0 to 1); this is part of the third module described hereafter.

ALT.	RUS	RWS	TP
Alt. 1	3	95	14
Alt. 2	50	50	11
Alt. 3	15	40	8
…	…	…	…
Alt. n	18	95	22

Table 2: Illustration of an evaluation table (alternative number + criteria)

Module III. Multicriteria Solver Module

Solving a multicriteria problem starts with identifying the most efficient solutions of the problem (i.e. the best candidates with respect to the constraints and the nature of the problem). The efficiency of a solution (an alternative) is here measured on the basis of the **dominance principle**; meaning that if a solution is dominated by another, it is removed from the set of solutions. Within the STARs evaluation tool, this step is achieved by making pairwise comparisons of the evaluations obtained by the alternatives on the three criteria.

In a concrete multicriteria problem with several criteria and a large set of alternatives, most of the solutions are efficient because of the poverty of the dominance relation. Then, to solve the multicriteria problem, you may need to use heuristic model which are complex and time-consuming problem solver. In STARs, there is a limited set of criteria and a quantifiable design space. Therefore, the dominance relation remains quite strong and allows inefficient alternatives to be excluded and to some extent the most promising ones to be highlighted. Finally, the remaining alternatives constitute the set of efficient solutions.

Ranking the efficient alternatives is difficult and as usual in MCDA methods additional information is necessary in order to reduce the number of "incomparabilities" and then solve the problem. Within STARs the additional information is provided by the use of **utility**

functions[1] to aggregate the 3 independent scores and finally rank the alternatives.

Utility functions play two important roles. Firstly they model the preferences on each criterion by expressing the scores in a common unit-less score (from 0 to 1). Within the STARs evaluation tool each utility function is characterised by a **marginal utility function** that shapes a performance function for each criterion and transforms rough scores from the Evaluation table into unit-less and comparable scores. These comparable scores are then further used as reference to attribute the 'stars rating'.

The utility based method was chosen not only because the concept is appropriate for ranking problems, but also because it is definitely user-friendly and the aggregation procedure is understandable even by a user not expert in multicriteria decision tools. Moreover the use of marginal utility functions gives the opportunity to easily later calibrate the evaluation tool to local constraints.

However, the development of the marginal utilities are quite complex. Which form should be given to these functions? Which parameters should be used? How could the preferences of the decision maker be expressed? All of these questions were considered by the partners during the development of the evaluation tool.

The work achieved within the project provided the following marginal utility functions. For each criterion, we have defined a utility function divided into 5 sections. Each section corresponds to a "star" class and it is defined by a threshold value. Consequently, the development of the marginal utility function had been mainly related to the definition of the thresholds associated to each class. To do so, several analyses have been conducted on the risk equations (RWS, RUS and TP) in order to identify the values of risk associated with different levels of performance. Moreover, the statistical behaviour of the risk equations has been studied in order to define accurate, relevant and not "too rewarding" thresholds.

At first, the meaning of the classes is defined as follows:

- 1 STAR class: very low performance
- 2 STARs class: low performance
- 3 STARs class: average performance
- 4 STARs class: good performance
- 5 STARs class: excellent performance

Then, the following thresholds are defined for each risk function:

Class	Utility value	RUS[2] (R)	RWS (R)	TP (t)
5 STARs	[1,0 ; 0,8 [	$1{,}0E^{-6} \leq R < 3{,}0E^{-6}$	$0{,}00 \leq R < 0{,}15$	$t < 6{,}1E^{-4}$
4 STARs	[0,8 ; 0,6 [	$3{,}0E^{-6} \leq R < 6{,}0E^{-6}$	$0{,}15 \leq R < 0{,}25$	$6{,}1E^{-4} \leq t < 0{,}03$
3 STARs	[0,6 ; 0,4 [	$6{,}0E^{-6} \leq R < 3{,}0E^{-5}$	$0{,}25 \leq R < 0{,}60$	$0{,}03 \leq t < 1{,}08$
2 STARs	[0,4 ; 0,2 [	$3{,}0E^{-5} \leq R < 5{,}0E^{-5}$	$0{,}60 \leq R < 0{,}75$	$1{,}08 \leq t < 73{,}70$
1 STAR	[0,2 ; 0,0]	$5{,}0E^{-5} \leq R < 1{,}0E^{-4}$	$0{,}75 \leq R < 1{,}00$	$t > 73{,}70$

Table 3: Thresholds for risk functions

[1] Utility based methods are complete aggregation methods. They are based on the use of utility functions which aggregate the value of all the actions on every criterion to form a single function.

[2] If an evaluation on the criterion RUS is greater than the upper threshold of the class 5 STARs (resp. smaller than the lower threshold of the class 1 STAR) then it obtains an utility value of 1,0 (resp. 0,0)

And finally the following utility functions are obtained:

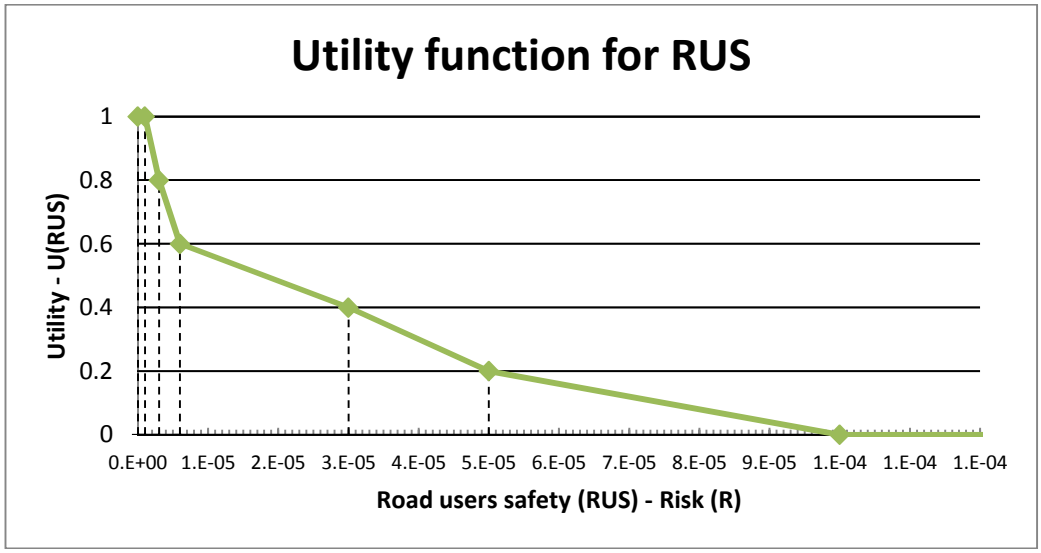


Figure 2: Utility function for road user safety (RUS)

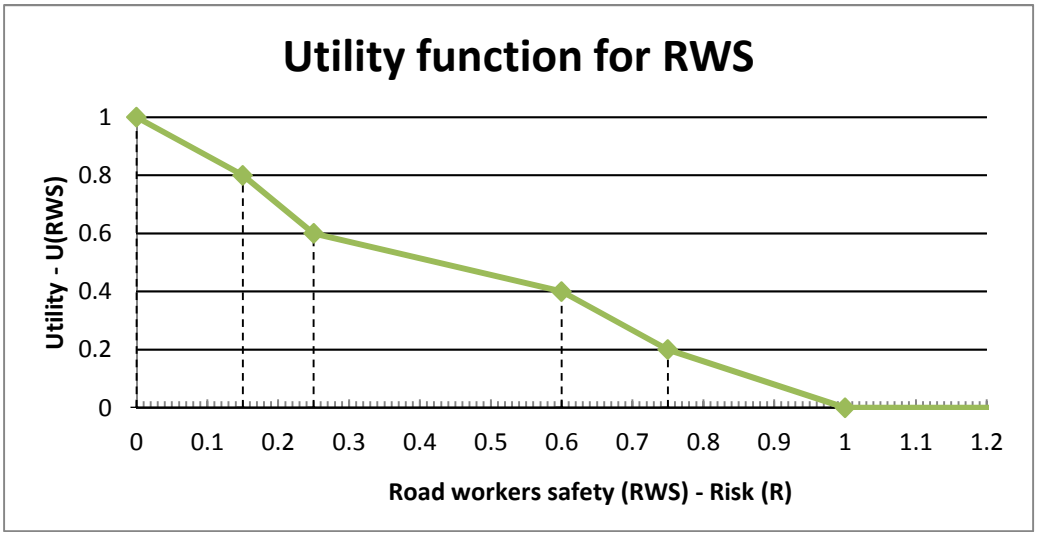


Figure 3: Utility function for RWS

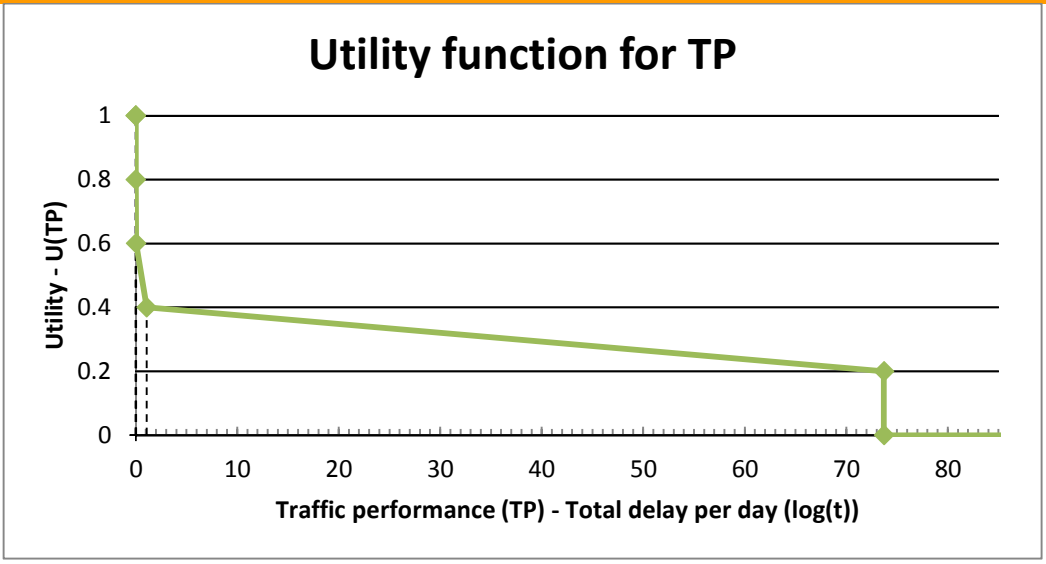


Figure 4: Utility function for TP

The last objective of the STARs Road Works Evaluation Tool is to propose a **single global star rating**; using the three individual scores on road user safety, road worker safety and network performance. Classically utility based methods use **weights** associated to each marginal utility function.

Again in view of giving flexibility for further development and customisation, it was decided to apply a simple additive form to aggregate the utility functions and to allow the decision maker to associate the set of weights with each criterion. The weights give the relative importance of each criterion so that (40%; 40%; 20%) would give twice as much importance to the first criterion. In the tool the default weighting assigns equal importance to each criterion (33%,33%,33%), but this can be changed by the user.

3 How to use the tool

To use the tool the user must first open the ‘STARs evaluation tool’ excel file (note that the STARs EvaluationCriteria file must be in the same folder in order to run the calculations and must have the same version number). To start an assessment the user presses the button "Calculate all alternatives"; the additional button on this startup screen is used to manually run the dominance calculations on an existing results file and will not usually be used.

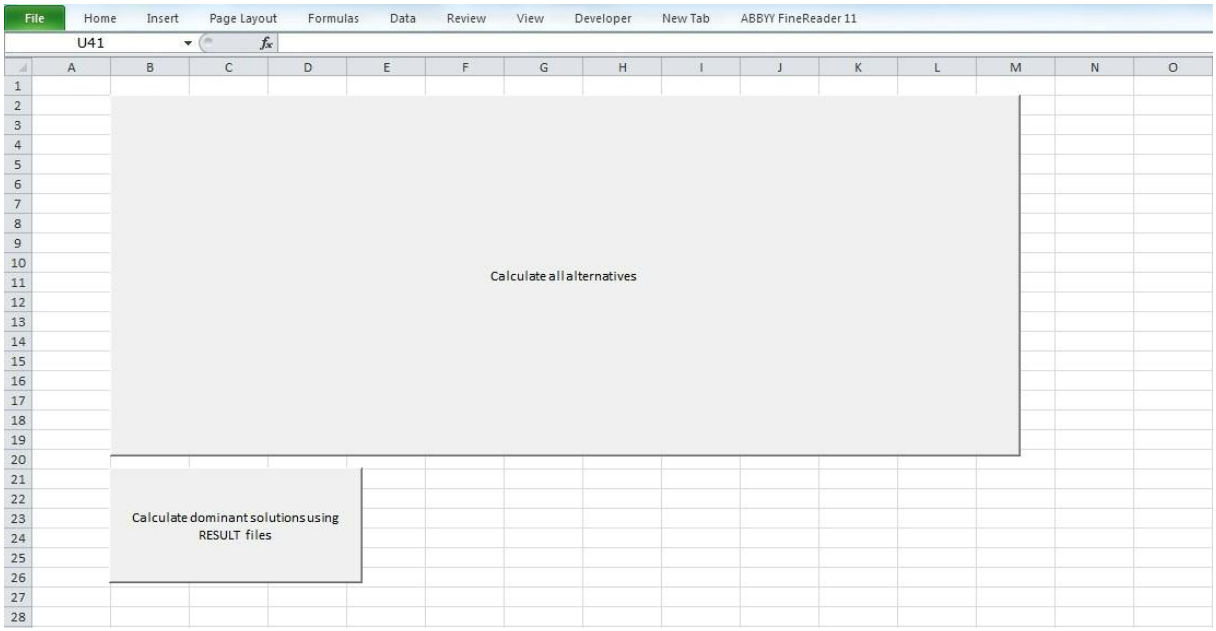


Figure 5: STARs tool start screen

Pressing the “Calculate all alternatives” button then produces a pop-up requesting the user to input the basic specifications of the considered motorway and types of work zone types. In the current version only motorways with 2- and 3-lane carriageways (2x2, 2x3) are included. Due to the fundamental differences between road works types, at this point a distinction in major, minor, and mobile work zones is made.

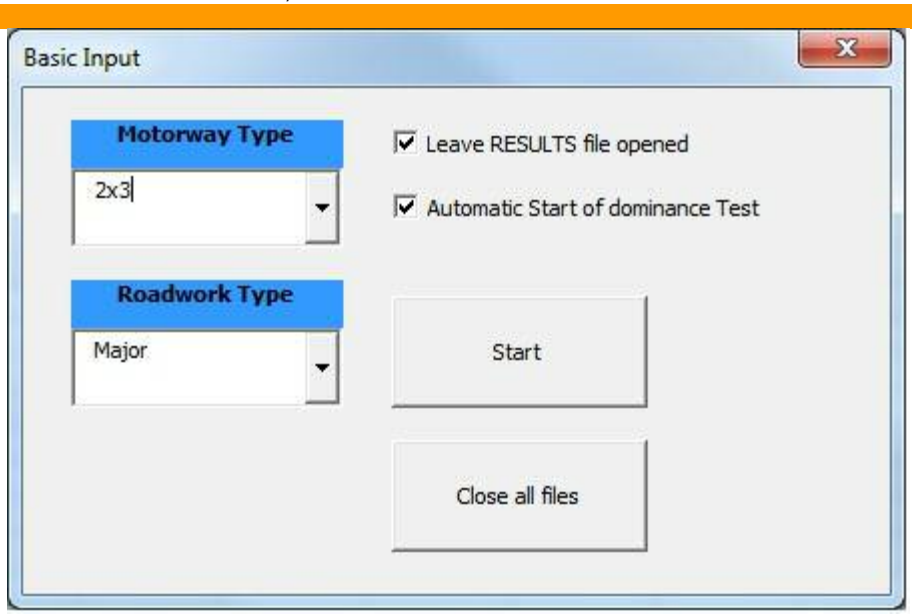


Figure 6: First user input screen

Two checkboxes are also provided on this screen: if 'Leave RESULTS file opened' is unchecked then the results spreadsheet created by the tool will be saved and closed once the calculations are completed, if 'Automatic Start of Dominance Test' is unchecked then the dominance calculation will not be performed on the 'alternatives' (i.e. they will not be ranked). If the dominance calculation is not carried out automatically, it can be done manually using the button on the first control screen (see Figure 5). Both boxes should be checked for normal operation of the tool.

Once selections have been made, the user presses the 'Start' button and the parameter selection screen shown in Figure 7 is now displayed. By using the first tick box per row the user can set whether the parameter is variable for the calculating of alternatives or not. Depending on the workzone type, these tick boxes may be automatically disabled, if the parameter is not relevant for that works type.

For fixed parameters exactly one ticked value (on the right hand side) is necessary. For variable parameters more than one value can be ticked. By using the first button "Check total nr. of alternatives" the user can check the number of ticked values per fixed parameters and the theoretical number of alternatives will be precalculated and shown. The more alternatives have to be calculated the longer this process takes. It is highly recommended that the user make this check before running the calculation. The button "Calculation" leads to the calculation process itself. (To leave the form and return to the main menu, the button 'STOP' can be used,)

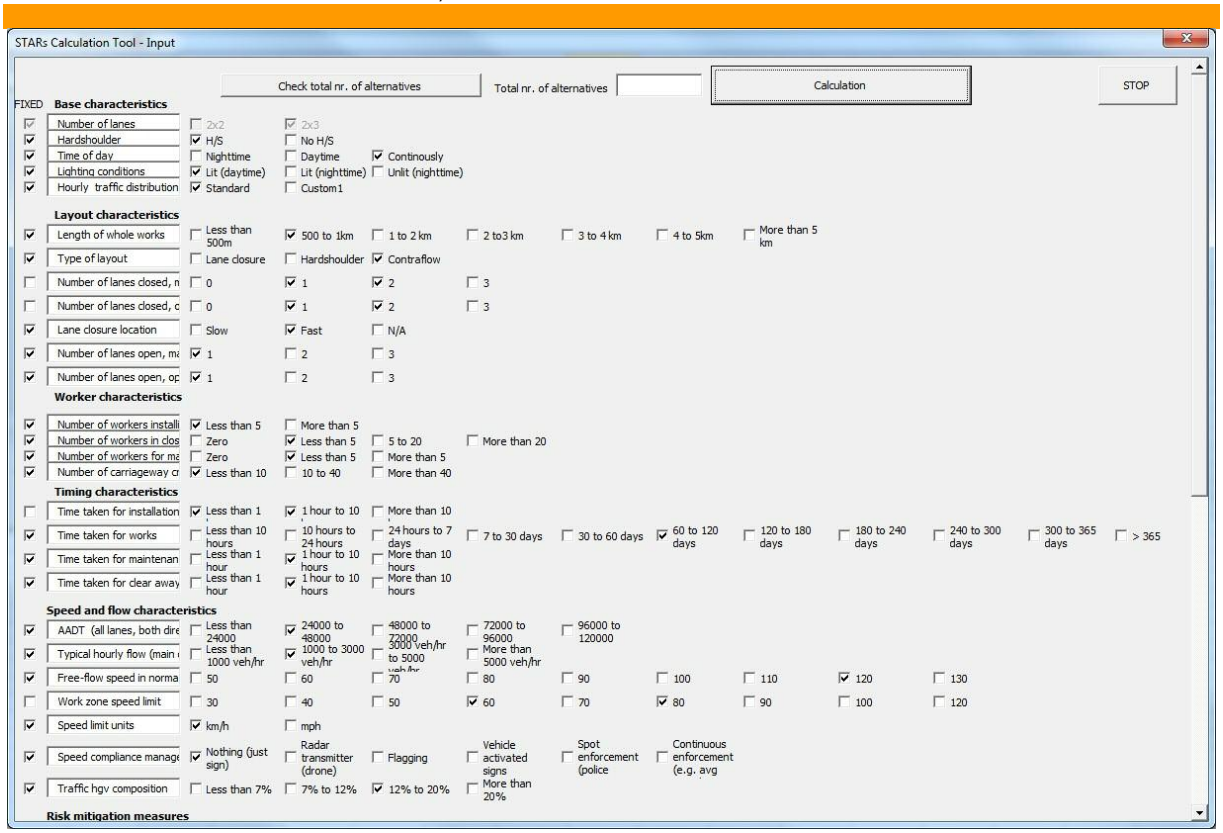
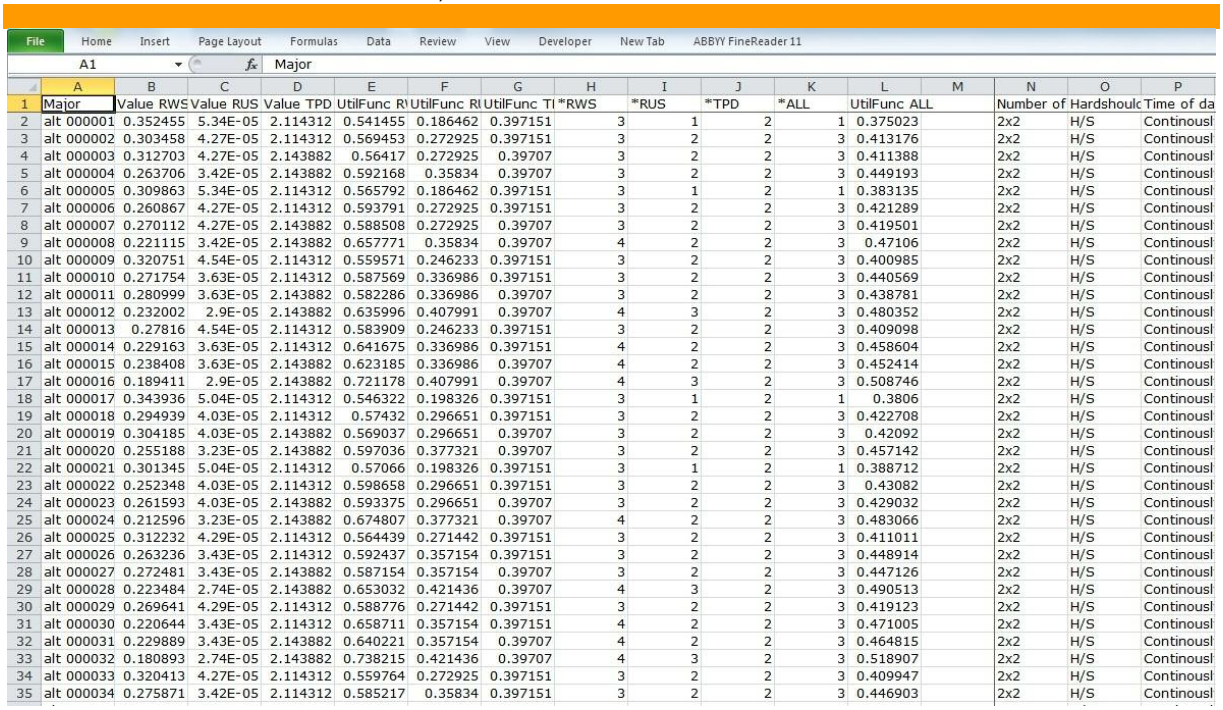


Figure 7: Parameter selection screen

The results of the calculation are then written to a file named “RESULTS” followed by the motorway and roadwork type and date and time of calculating, which is saved in the same folder as the tool spreadsheet. If the dominance calculation has not been selected to run automatically then the process stops at this point. Otherwise, the dominance calculation will also be performed on the set of alternatives and the output also written to the RESULTS file.

Assuming the latter to be the case, and assuming the user has also checked the box to ‘leave the RESULTS file opened’, once the calculations are complete the user will be presented with the RESULTS file. (If the user has not opted to leave the RESULTS file open, then the calculations will still be carried out and saved to the file.)

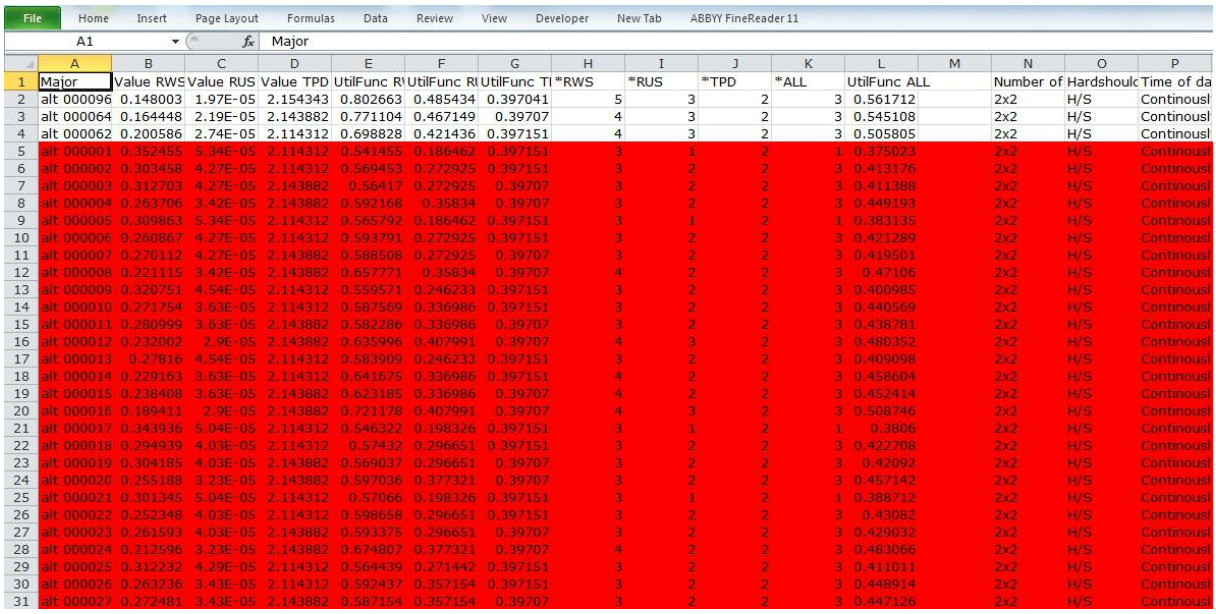
This has three worksheets: ‘Results’, ‘Dominance’ and ‘Summary dominant solutions’. The ‘Results’ worksheet lists all the possible alternatives with the users choice of fixed and variable parameters. The relevant scores for road worker safety, road user safety and traffic performance are documented in absolute values, followed by the utility function values, the ‘STARs score for each, the overall STARs rating and finally the aggregated utility value (depending on the weights associated to each criteria). The remaining columns list the input data for each alternative.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Major	Value RWS	Value RUS	Value TPD	UtilFunc R	UtilFunc RU	UtilFunc TI	*RWS	*RUS	*TPD	*ALL	UtilFunc ALL		Number of	Hardshoulc	Time of da
2	alt 000001	0.352455	5.34E-05	2.114312	0.541455	0.186462	0.397151	3	1	2	1	0.375023		2x2	H/S	Continousl
3	alt 000002	0.303458	4.27E-05	2.114312	0.569453	0.272925	0.397151	3	2	2	3	0.413176		2x2	H/S	Continousl
4	alt 000003	0.312703	4.27E-05	2.143882	0.56417	0.272925	0.39707	3	2	2	3	0.411388		2x2	H/S	Continousl
5	alt 000004	0.263706	3.42E-05	2.143882	0.592168	0.35834	0.39707	3	2	2	3	0.449193		2x2	H/S	Continousl
6	alt 000005	0.309863	5.34E-05	2.114312	0.565792	0.186462	0.397151	3	1	2	1	0.383135		2x2	H/S	Continousl
7	alt 000006	0.260867	4.27E-05	2.114312	0.593791	0.272925	0.397151	3	2	2	3	0.421289		2x2	H/S	Continousl
8	alt 000007	0.270112	4.27E-05	2.143882	0.588508	0.272925	0.39707	3	2	2	3	0.419501		2x2	H/S	Continousl
9	alt 000008	0.221115	3.42E-05	2.143882	0.657771	0.35834	0.39707	4	2	2	3	0.47106		2x2	H/S	Continousl
10	alt 000009	0.320751	4.54E-05	2.114312	0.559571	0.246233	0.397151	3	2	2	3	0.400985		2x2	H/S	Continousl
11	alt 000010	0.271754	3.63E-05	2.114312	0.587569	0.336986	0.397151	3	2	2	3	0.440569		2x2	H/S	Continousl
12	alt 000011	0.280999	3.63E-05	2.143882	0.582286	0.336986	0.39707	3	2	2	3	0.438781		2x2	H/S	Continousl
13	alt 000012	0.232002	2.9E-05	2.143882	0.635996	0.407991	0.39707	4	3	2	3	0.480352		2x2	H/S	Continousl
14	alt 000013	0.27816	4.54E-05	2.114312	0.583909	0.246233	0.397151	3	2	2	3	0.409098		2x2	H/S	Continousl
15	alt 000014	0.229163	3.63E-05	2.114312	0.641675	0.336986	0.397151	4	2	2	3	0.458604		2x2	H/S	Continousl
16	alt 000015	0.238408	3.63E-05	2.143882	0.623185	0.336986	0.39707	4	2	2	3	0.452414		2x2	H/S	Continousl
17	alt 000016	0.189411	2.9E-05	2.143882	0.721178	0.407991	0.39707	4	3	2	3	0.508746		2x2	H/S	Continousl
18	alt 000017	0.343936	5.04E-05	2.114312	0.546322	0.198326	0.397151	3	1	2	1	0.3806		2x2	H/S	Continousl
19	alt 000018	0.294939	4.03E-05	2.114312	0.57432	0.296651	0.397151	3	2	2	3	0.422708		2x2	H/S	Continousl
20	alt 000019	0.304185	4.03E-05	2.143882	0.569037	0.296651	0.39707	3	2	2	3	0.42092		2x2	H/S	Continousl
21	alt 000020	0.255188	3.23E-05	2.143882	0.597036	0.377321	0.39707	3	2	2	3	0.457142		2x2	H/S	Continousl
22	alt 000021	0.301345	5.04E-05	2.114312	0.57066	0.198326	0.397151	3	1	2	1	0.388712		2x2	H/S	Continousl
23	alt 000022	0.252348	4.03E-05	2.114312	0.598658	0.296651	0.397151	3	2	2	3	0.43082		2x2	H/S	Continousl
24	alt 000023	0.261593	4.03E-05	2.143882	0.593375	0.296651	0.39707	3	2	2	3	0.429032		2x2	H/S	Continousl
25	alt 000024	0.212596	3.23E-05	2.143882	0.674807	0.377321	0.39707	4	2	2	3	0.483066		2x2	H/S	Continousl
26	alt 000025	0.312232	4.29E-05	2.114312	0.564439	0.271442	0.397151	3	2	2	3	0.411011		2x2	H/S	Continousl
27	alt 000026	0.263236	3.43E-05	2.114312	0.592437	0.357154	0.397151	3	2	2	3	0.448914		2x2	H/S	Continousl
28	alt 000027	0.272481	3.43E-05	2.143882	0.587154	0.357154	0.39707	3	2	2	3	0.447126		2x2	H/S	Continousl
29	alt 000028	0.223484	2.74E-05	2.143882	0.653032	0.421436	0.39707	4	3	2	3	0.490513		2x2	H/S	Continousl
30	alt 000029	0.269641	4.29E-05	2.114312	0.588776	0.271442	0.397151	3	2	2	3	0.419123		2x2	H/S	Continousl
31	alt 000030	0.220644	3.43E-05	2.114312	0.658711	0.357154	0.397151	4	2	2	3	0.471005		2x2	H/S	Continousl
32	alt 000031	0.229889	3.43E-05	2.143882	0.640221	0.357154	0.39707	4	2	2	3	0.464815		2x2	H/S	Continousl
33	alt 000032	0.180893	2.74E-05	2.143882	0.738215	0.421436	0.39707	4	3	2	3	0.518907		2x2	H/S	Continousl
34	alt 000033	0.320413	4.27E-05	2.114312	0.559764	0.272925	0.397151	3	2	2	3	0.409947		2x2	H/S	Continousl
35	alt 000034	0.275871	3.42E-05	2.114312	0.585217	0.35834	0.397151	3	2	2	3	0.446903		2x2	H/S	Continousl

Figure 8: Example of 'Results' worksheet

The ‘Dominance’ worksheet displays the outcome of the dominance calculations; the dominant solutions are shown at the top of the worksheet (in white), whilst all the non-dominant solutions are shown below (in red). The dominant solutions are also ranked according to their aggregated score.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Major	Value RWS	Value RUS	Value TPD	UtilFunc R	UtilFunc RU	UtilFunc TI	*RWS	*RUS	*TPD	*ALL	UtilFunc ALL		Number of	Hardshoulc	Time of da
2	alt 000096	0.148003	1.97E-05	2.154343	0.802663	0.485434	0.397041	5	3	2	3	0.561712		2x2	H/S	Continousl
3	alt 000064	0.164448	2.19E-05	2.143882	0.771104	0.467149	0.39707	4	3	2	3	0.545108		2x2	H/S	Continousl
4	alt 000062	0.200586	2.74E-05	2.114312	0.698828	0.421436	0.397151	4	3	2	3	0.505805		2x2	H/S	Continousl
5	alt 000001	0.352455	5.34E-05	2.114312	0.541455	0.186462	0.397151	3	1	2	1	0.375023		2x2	H/S	Continousl
6	alt 000002	0.303458	4.27E-05	2.114312	0.569453	0.272925	0.397151	3	2	2	3	0.413176		2x2	H/S	Continousl
7	alt 000003	0.312703	4.27E-05	2.143882	0.56417	0.272925	0.39707	3	2	2	3	0.411388		2x2	H/S	Continousl
8	alt 000004	0.263706	3.42E-05	2.143882	0.592168	0.35834	0.39707	3	2	2	3	0.449193		2x2	H/S	Continousl
9	alt 000005	0.309863	5.34E-05	2.114312	0.565792	0.186462	0.397151	3	1	2	1	0.383135		2x2	H/S	Continousl
10	alt 000006	0.260867	4.27E-05	2.114312	0.593791	0.272925	0.397151	3	2	2	3	0.421289		2x2	H/S	Continousl
11	alt 000007	0.270112	4.27E-05	2.143882	0.588508	0.272925	0.39707	3	2	2	3	0.419501		2x2	H/S	Continousl
12	alt 000008	0.221115	3.42E-05	2.143882	0.657771	0.35834	0.39707	4	2	2	3	0.47106		2x2	H/S	Continousl
13	alt 000009	0.320751	4.54E-05	2.114312	0.559571	0.246233	0.397151	3	2	2	3	0.400985		2x2	H/S	Continousl
14	alt 000010	0.271754	3.63E-05	2.114312	0.587569	0.336986	0.397151	3	2	2	3	0.440569		2x2	H/S	Continousl
15	alt 000011	0.280999	3.63E-05	2.143882	0.582286	0.336986	0.39707	3	2	2	3	0.438781		2x2	H/S	Continousl
16	alt 000012	0.232002	2.9E-05	2.143882	0.635996	0.407991	0.39707	4	3	2	3	0.480352		2x2	H/S	Continousl
17	alt 000013	0.27816	4.54E-05	2.114312	0.583909	0.246233	0.397151	3	2	2	3	0.409098		2x2	H/S	Continousl
18	alt 000014	0.229163	3.63E-05	2.114312	0.641675	0.336986	0.397151	4	2	2	3	0.458604		2x2	H/S	Continousl
19	alt 000015	0.238408	3.63E-05	2.143882	0.623185	0.336986	0.39707	4	2	2	3	0.452414		2x2	H/S	Continousl
20	alt 000016	0.189411	2.9E-05	2.143882	0.721178	0.407991	0.39707	4	3	2	3	0.508746		2x2	H/S	Continousl
21	alt 000017	0.343936	5.04E-05	2.114312	0.546322	0.198326	0.397151	3	1	2	1	0.3806		2x2	H/S	Continousl
22	alt 000018	0.294939	4.03E-05	2.114312	0.57432	0.296651	0.397151	3	2	2	3	0.422708		2x2	H/S	Continousl
23	alt 000019	0.304185	4.03E-05	2.143882	0.569037	0.296651	0.39707	3	2	2	3	0.42092		2x2	H/S	Continousl
24	alt 000020	0.255188	3.23E-05	2.143882	0.597036	0.377321	0.39707	3	2	2	3	0.457142		2x2	H/S	Continousl
25	alt 000021	0.301345	5.04E-05	2.114312	0.57066	0.198326	0.397151	3	1	2	1	0.388712		2x2	H/S	Continousl
26	alt 000022	0.252348	4.03E-05	2.114312	0.598658	0.296651	0.397151	3	2	2	3	0.43082		2x2	H/S	Continousl
27	alt 000023	0.261593	4.03E-05	2.143882	0.593375	0.296651	0.39707	3	2	2	3	0.429032		2x2	H/S	Continousl
28	alt 000024	0.212596	3.23E-05	2.143882	0.674807	0.377321	0.39707	4	2	2	3	0.483066		2x2	H/S	Continousl
29	alt 000025	0.312232	4.29E-05	2.114312	0.564439	0.271442	0.397151	3	2	2	3	0.411011		2x2	H/S	Continousl
30	alt 000026	0.263236	3.43E-05	2.114312	0.592437	0.357154	0.397151	3	2	2	3	0.448914		2x2	H/S	Continousl
31	alt 000027	0.272481	3.43E-05	2.143882	0.587154	0.357154	0.39707	3	2	2	3	0.447126		2x2	H/S	Continousl

Figure 9: Example of 'Dominance' worksheet

The ‘Summary dominant solutions’ worksheet displays all dominant solutions in terms of their score, and the values taken by the variable parameters that resulted in that score. This provides the user with clear information of the best options for the road works in question and how that can be achieved, in terms of the variable parameters selected.

	1		2		3	
Dominant Solutions	alt 000096		alt 000064		alt 000062	
Overall Stars Rating	* * *	0.5617125	* * *	0.54510763	* * *	0.50580516
Road User Safety	* * *	0.48543369	* * *	0.46714855	* * *	0.42143568
Road Worker Safety	* * * * *	0.80266261	* * * *	0.77110435	* * * *	0.69882836
Traffic Performance	* *	0.39704119	* *	0.39707	* *	0.39715144
Variable Parameters						
Speed compliance managemen	Spot enforcement (police		Vehicle activated signs		Vehicle activated signs	
Delineation	Temporary barrier		Temporary barrier		Temporary barrier	
Lane closure mechanism	Both		Both		Both	
Use of vehicle restraint system	Low performance		Low performance		Low performance	
Use of physical traffic managen	Transverse pavement mai		Transverse pavement mai		None	
Use of TMA/LMCC	1		1		1	

Figure 10: Example of 'Summary dominant solutions' worksheet

It may be of interest to also consider the number of such dominant solutions - a small number of dominant solutions indicates that the final choice is less dependent on the preferences of the decision maker (i.e. weights associated to each criteria + nature of the dominance relation + integration of constraints).

The tool can in theory be customised using the 'STARs EvaluationCriteria' file. This contains one worksheet per workzone type with default settings for typical layouts and variable parameter settings. To use customised settings the user can copy and change these worksheets. For the use of the tool it is necessary that each one sheet with exactly name "Major", one with name "Minor" and one with name "Mobile" are available. This is so the tool can be tailored to an individual country in terms of fixed and variable parameters – for some countries, standards and legislation will dictate certain parameters to be fixed, whilst in others the same parameters can be varied. Changing these settings means that the user would not need to input these defaults for each use of the tool. Choosing the workzone type when running the tool copies the content of the relevant worksheet into the input-sheet "i" where the default settings being used are visible.

The relative weighting of the three criteria can also be customised on the 'Results' worksheet in the STARs Evaluation Criteria file, by inputting different values into the table at the top of the sheet.

Although customisation of the tool is possible through modification of this file, it has not been designed for the general user to do so, and it is highly recommended that the STARs EvaluationCriteria is not modified without full understanding of the workings of the tool. If it is modified, the file version number must match that of the STARs tool.

4 Parameter user guidance

This aim of this section is to provide guidance for the user for each individual parameter input to the tool. Examples and illustrations are given for some parameters to provide clarification.

The tool has also been designed to be broadly applicable across different countries; therefore some options may be irrelevant to the user, others may be aggregated in a way that is not directly relevant to their country. User may also find that options are available that are contrary to their country's legislation or current best practice. In such cases, it is intended that the user use their own best judgement to decide which option is most appropriate. It should be noted that the tool is designed to provide only a representative assessment of road works schemes and that the results are intended to be used primarily for comparative purposes.

Base characteristics

Parameter: Number of lanes
Options: 2x2; 2x3
The user should select 2x2 if the works are being carried out on a two-lane motorway or 2x3 for a three-lane motorway.

Parameter: Hardshoulder
Options: H/S; No H/S
The user should select H/S if there is a hard shoulder on the stretch of motorway where (and when) the works are taking place, and no H/S if there is not. Hard shoulder in this context is a paved strip beside a motorway for vehicles stopping in emergencies to be off the main carriageway. This parameter is important from the Road Worker safety perspective (it is safer for workers to have somewhere to lay out traffic management from etc.), if the paved strip is not sufficiently wide to allow a traffic management vehicle to pull out of the live traffic lane then the user should select 'no H/S'.

Parameter: Time of day
Options: Continuously, Night-time; Daytime
The user should select one of the options depending on used the work zone scheduling. A continuous work zone means it is deployed during full day and during the whole time taken for the road work. A night-time work zone is performed only during the night time (in the tool it is set to be from 7 pm to 6 am by default) and removed during the rest of day. A daytime work is only carried out during the day shift hours

Parameter: Lighting conditions
Options: Lit (daytime); Lit (night-time); Unlit (night-time)
The user should select the lighting conditions that will be present for the majority of the works. If the works run continuously and equally for both day and night then one of the night-time options (either lit or unlit) should be selected. ‚Lit' means regularly-spaced street lamps or equivalent are provided either along the sides or centre of the carriageway.

Parameter: Hourly traffic distribution
Options: Standard; Custom
The user should select one of the options for which hourly distribution to use. A simplified distribution has been assumed for the Standard option. (If the user wants to use a custom

hourly distribution this can be defined in the TPData sheet (to be found in the STARs EvaluationCriteria file) and then the Custom option can be selected.)

The Standard traffic hourly distribution used in the tool is as follows:

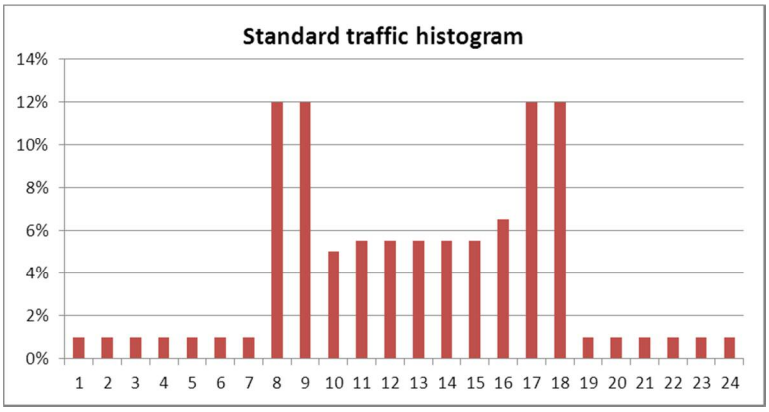


Figure 11:Standard traffic hourly distribution

Layout characteristics

Parameter: Length of whole works
Options: Less than 500m; 500 to 1km; 1 to 2 km; 2 to3 km; 3 to 4 km; 4 to 5km; More than 5 km
The user should estimate the total length of the works. This consists of the length of the regulation advance warning and transition area, the activity area and the length of the termination area. The length of the whole works does not include the Far advance warning, length of which is accounted for in the Risk Mitigation Measures below.

As an example, the length of the regulation advance warning zone to use when considering Belgian works regulations is as follows:

- For major and minor works, the regulation advance warning starts with the first warning signs:

  - used with a flashing-light and the message “Queue possible”. It is located between 1500m and 3000m upstream and can be included in the following large framesign:

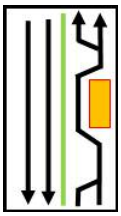
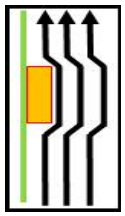
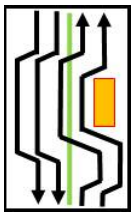
- For mobile works, the first warning signs are:

  - both are fixed in the same large frame sign and are located 500 upstream the first safety vehicle.

Any additional “far advance warning” provided upstream through VMS (fixed or mobile) or even using non-variable signs (on bridges or gantries) should not be considered as part of the road works length.

Parameter: Type of layout

Options: Lane closure; Hard shoulder; Contraflow

The user should select a road work layout type. Lane closure means that one (or more) lane(s) is (are) closed and traffic switched to one of the open lanes. Hard shoulder means one of the hard shoulders is used for traffic. Finally, a contraflow layout has at least one lane diverted to the opposite direction.

Parameter: Number of lanes closed, main direction

Options: 0; 1; 2; 3

The user should input the number of lanes closed on the carriageway where the road works are carried out (i.e. the main direction). If all the lanes of the main carriageway are closed (and even if a contraflow layout is installed) the user should input the original number of lanes. Note that it is possible for the number of closed lanes and number of open lanes to equal more than the total number of lanes – for example if a single lane is closed on a three-lane road but the three lanes of traffic remain but are shifted to the right.

Parameter: Number of lanes closed, opposite direction

Options: 0; 1; 2; 3

Note: This parameter is not relevant for mobile or minor works and will be disabled.

The user should input the number of lanes closed on the opposite carriageway (i.e. where the road works are not being carried out). A reduction of the number of open lanes only happen when a contraflow layout is installed.

Parameter: Lane closure location

Options: Slow; Fast, N/A

The user should select one of the options based on road work's lane closure location. On three lane motorways the second and third lanes are both considered to be fast lanes.

- If the road works impact the slow lane only, the user should select "Slow";
- If the road works impact the fast lane only, the user should select "Fast";
- If the road works impact the slow and median lanes on a 3 lanes motorway, the user should select "Slow";
- If the road works impact the fast and median lanes on a 3 lanes motorway, the user should select "Fast";
- If the road works impact the whole carriageway, the user should select "Slow".
- If there are no lane closures the user should select 'N/A'

Parameter: Number of lanes open, in main direction

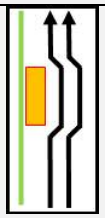
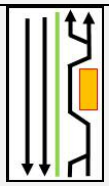
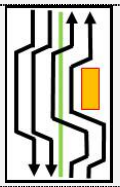
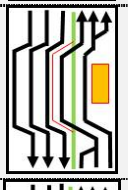
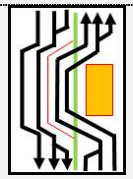
Options: 1; 2; 3

The user should input the number of lanes of traffic that remain open past the works. This is regardless of whether the lanes that remain open are narrow or in a contraflow formation.

Parameter: Number of lanes open in opposite direction

Options: 1; 2; 3

The user should input the number of lanes of traffic that remain open past the works for users travelling in the opposite direction.

Examples*	Type of layout	Lanes closed, main direction	Lanes closed, opposite direction	Lane closure location	Lanes open, main direction	Lanes open, opposite direction
	Lane closure	1	0	Fast	2	2
	Lane closure	1	0	Slow	1	2
	Contraflow	1	0	Slow	2	2
	Contraflow	2	0	Slow	2	3
	Contraflow	3	1	Slow	2	2

**: These layouts refer to road works examples in Left hand-side driving countries*

Table 4: Examples of parameter input for different layouts

Worker characteristics

Parameter: Number of workers installing/clearing

Options: Less than 5; More than 5

The user should estimate how many workers are required to set out and retrieve the traffic management for the works. This includes the drivers of vehicles involved in setting out or retrieval of traffic management equipment e.g. signs etc.

Parameter: Number of workers in closure

Options: Less than 5; 5 to 20; More than 20

The user should estimate how many workers will be required to carry out the works themselves and will be present in the closure and exposed to risk. This refers to those

workers undertaking repairs etc. for which the temporary traffic management and work zone has been set out.

Parameter: Number of workers for maintenance

Options: Less than 5; More than 5

Note: This parameter is not relevant for mobile works and will be disabled.

Maintenance of the roadworks refers to the time during which the temporary traffic management is checked to ensure that the signing etc. is still correctly displayed and in good condition. The user should estimate the number of workers likely to be required for this task.

Parameter: Number of carriageway crossings

Options: Less than 10; 10 to 40; More than 40

'Crossings' refers to a road worker moving across live traffic lanes to place temporary traffic management signs, etc. 'One crossing' is when the road worker crosses the live lanes in one direction. Returning across the lives lanes is a second crossing. The user should estimate how many carriageway crossings are likely to be required for the setting out and clearing away of the works.

Timing characteristics

Parameter: Time taken for installation

Options: Less than 1 hour; 1 hour to 10 hours; More than 10 hours

This is the time from when the first vehicle makes its first stop, or arrives at the works site to begin setting out, to the time when it leaves the works site when the works site is completely set out. The user should estimate which option is closest to the expected time taken.

Parameter: Time taken for works

Options: Less than 10 hours; 10 hours to 24 hours; 24 hours to 7 days; 7 to 30 days; 30 to 60 days; 60 to 120 days; 120 to 180 days; 180 to 240 days; 240 to 300 days; 300 to 365 days; >365

This refers to the time taken to carry out the works for which the temporary traffic management and work zone has been set out, and is the time for the duration of the works activity. The user should select which option is closest to the expected time taken.

Parameter: Time taken for maintenance

Options: Less than 1 hour; 1 hour to 10 hours; More than 10 hours

Note: This parameter is not relevant for mobile works and will be disabled.

Maintenance time is the time during which the temporary traffic management is checked to ensure that the signing etc. is still correctly displayed and in good condition. The user should estimate the length of time that will be required to carry out this activity.

Parameter: Time taken for clear away

Options: Less than 1 hour; 1 hour to 10 hours; More than 10 hours

This is the time from when the works are completed, to the time when it leaves the works site when the works site is completely cleared away. The user should estimate which option is closest to the expected time taken.

Speed and flow characteristics

Parameter: AADT (total flow for the carriageway, all lanes, both directions)
Options: Less than 24000; 24000 to 48000; 48000 to 72000; 72000 to 96000; 96000 to 120000
The user should select the option which is closest to the AADT (Average Annual Daily Traffic) value for the road in question.

Parameter: Typical hourly flow (total flow for the carriageway in the main direction only)
Options: Less than 1000 veh/hr; 1000 to 3000 veh/hr; 3000 veh/hr to 5000 veh/hr; More than 5000 veh/hr
The user should select the option which is closest to estimated typical hourly flow for all lanes on the main carriageway only during the time the roadworks are in place. If this is likely to vary significantly, the highest value should be used (representing a worst-case scenario). Note: if a typical hourly flow is not known, the user can estimate this as 5-8 % of the AADT (as defined above) for peak hour works, approx 0.5 % for nightly works and 3 to 5% for daily works.

Parameter: Free-flow speed in normal conditions
Options: User input only
User should input a representative speed for traffic on the road in question. Note that this is not necessarily equal to the normal speed limit on the road.

(Also note the selection of speed limit units below.)

Parameter: Work zone speed limit
Options: 30; 40; 50; 60; 70; 80; 90; 100; 120
Note that some countries have a standard work zone speed limit for all work zones and the national standards should be consulted to ensure compliance with country practices. It is recommended that the speed limit is set to be safe enough for the temporary layout but not reduced excessively or unnecessarily; for a motorway with a usual speed of 120km/h, the speed limit in a work zone should be reduced by a maximum of two speed limit steps and this can be reduced further at specific locations (such as a crossover) if necessary. The speed limit of the work zone should be used here, even if the speed limit in the taper area is lower than the speed limit along the work zone (this happens typically when the central reserve is crossed for a contraflow layout).

Parameter: Speed limit units
Options: km/h; mph
The user should select either km/h or mph depending in which units the preceding parameters (Free-flow speed in normal conditions on road and Work zone speed limit) have been input.

Parameter: Speed compliance management
Options: Nothing (just sign); Radar transmitter (drone); Flagging; Vehicle activated signs; Spot enforcement (police presence, spot speed cameras); Continuous enforcement/Section control (i.e. average speed cameras)

The user should make a judgement regarding the level of control or enforcement for the speed limit through the work zone. If more than one form of compliance management is

used, then the higher level of control/enforcement should be selected. The options are described in more detail below:

Nothing (just sign) – In this situation, there is no enforcement of the speed limit. The driver is advised of the limit via signs but nothing more. All speed compliance management systems should result in a safer work zone than signs only.

Figure 12: Speed limit signs only

Radar transmitter (drone) – Drone radar emitters are also an option and have the advantage of being low cost and easily moved. However, they do not actually measure a vehicles speed. A drone radar transmitter is a small, lightweight, weatherproof device that is equipped with a sensor that activates radar detectors in vehicles. They are used to make drivers with radar detectors think that there is police presence in the area. They therefore work as a warning or deterrent to drivers with radar detectors in their vehicles.

Figure 13: An in-vehicle speed limit detection device

Flagging – Flagging can be used to warn road users of upcoming roadworks. Flaggers are placed at safe locations to motion to drivers to slow down. The flagger should be placed far enough in advance of the work zone to allow road users to respond appropriately i.e. stop or slow down. As supposed by the following illustrations manual flagging is usually not used on motorways.

Figure 14: Illustrations of flagging (right picture - source: www.wegenforum.nl)

However automatic flagging systems are being used in some countries.

Vehicle activated signs – Vehicle activated signs are used to alert drivers to the actual speed they are travelling at. Fixed or mobile systems are both used.

Figure 15: Vehicle-activated sign

Spot enforcement (police presence, spot speed cameras) – Police enforcement is perceived to be one of the most successful methods of reducing road user speed through work zones. However there are some drawbacks in that, the same as flagging, it can be labour intensive and costly with long term use.

Figure 16: Spot enforcement

However semi-mobile speed cameras (installed for several days) are more and more used, typically for safety sensitive road work sites.

Continuous enforcement/Section control (e.g. avg speed cameras)- Section control is a continuous enforcement method that uses linked Automatic Number Plate Recognition (ANPR) cameras to monitor the speed of the traffic through a work zone. One camera continuously captures images of vehicles as they pass by. The number plates are read using ANPR and when the same vehicle is recorded by another camera connected to the system the average speed of the vehicle is calculated over the known distance between the cameras. If this speed exceeds the work zone speed limit an offence record is created and action can be taken using proof from the cameras and data logs.

Figure 17: Average speed check

Parameter: Traffic HGV composition
Options: Less than 7%; 7% to 12%; 12% to 20%; More than 20%
The user should estimate the likely composition of the passing traffic during the roadworks. This should be assumed to be the same as for the usual traffic on the road, taking into account any variations due to the time of day that the roadworks are taking place. Again, if it is likely to vary, then the higher value should be used.

Risk mitigation measures

Parameter: Far advance warning
Options: None; Sign (VMS or non-variable)

Most countries standard work zone practices require a road works ahead sign and provide recommended distances for this sign depending on the speed limit and road type. Advance warning, supplementing the standard road works warning signs, may be provided using either mobile or fixed VMS systems.

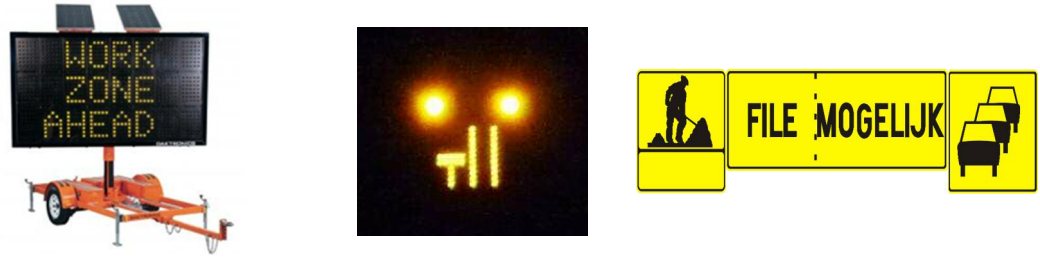


Figure 18: Examples of mobile and fixed VMS (left, middle) and non-variable sign (right) for far advance warning

Parameter: Far advance warning, length

Options: 500m; 1000m; 2500m

As discussed in the previous parameter, additional advance warning may be provided using VMS. The user should select the option that is closest to the distance between this advance warning and the start of the regulation advance warning and transition area

Parameter: Lateral distance between workzone and traffic

Options: Minimum; Standard; Above Standard

The lateral safety clearance is a used to separate workers from live traffic lanes and is the distance between the live traffic lane and the edge of the activity area itself. These should be based on published guidelines of a code of practice. The user should make a judgment based on these guidelines and select the most relevant option for the particular works.

If the country guidelines specify a minimum distance then chose ‘standard’ as this distance is the distance recommended by the standard of practice (typical standard lateral safety distances range from 0.5m to 2.5m). ‘Minimum’ should be selected if it is less than the guidelines recommendation.

Other (exceptional) situations, e.g. one lane fully used as buffer area between the work zone and the traffic, or all traffic sent to another carriageway, could be considered as “above standard”.

Parameter: Signage levels

Options: Minimum; Optimised; Optimised plus

For a particular roadwork, there is an important balance that must be found in relation to signage levels, in terms of both road user and road worker safety.

To optimise road user safety, adequate signs must be provided to ensure the driver is aware of the new layout and potential hazards, but not so many signs that will cause distraction.

To optimise road worker safety, again adequate signs must be provided to ensure that the road users are aware of the new layout and hazards and thereby provide less of a risk to workers, but not so many signs that the risk to workers of setting out the signs becomes unacceptable. (Note that this consideration only applies to signs that need to be physically placed on the carriageway by the workforce, and not signs displayed using fixed VMS signage.)

The user must make a judgment of how the signage levels should be rated, based on a consideration of these issues.

Figure 19: Examples of signage: Road workers placing temporary 'plate signs' (left) and an example of a VMS graphic display (right)

Example:

In Belgium, the federal decree of May 7th, 1999 establishes the “Minimum” requirements for signing of road work activities.

However, the regional standard tender specifications and their associated schemes provide some additional rules for signing of the more typical road works layouts. These additional rules usually result from a consultation of experts and practitioners who analysed both road worker's and road user's safety issues. A scheme designed to comply with the last update of the regional regulations could be considered as "Optimised"

When new technologies, like fixed or mobile VMS graphic display are used (complementarily or as dynamic signing) for road work signing (e.g. for advanced queue warning), the signage levels could be considered as "Optimised plus".

Parameter: Delineation
Options: None; Cones; Panels; Barrels; Cylinders; Temporary barrier; Permanent barrier; Other
Note: This parameter is not relevant for mobile works and will be disabled.

There are a number of options available for delineation of the workzone and the user should select the option that is most relevant to the works. Workplace delineation maintains clearance between passing traffic and the work force. It may be a system intended to prevent vehicles entering the work zone, or to give a visible 'edge'.

Cones, panels, barrels and cylinders do not prevent road workers from crossing into the path of passing traffic or protect road workers from errant vehicles. These options provide visual guidance only. However barrels and panels are larger and sturdier. Cone lines may be enhanced by using 'rope' or bars to provide warning to workers that they are close to the edge of the work zone.

Figure 20: Examples of delineation (left to right) cones, traffic barrel, cylinder, panel

Temporary and permanent barriers are intended to restrain errant vehicles, see also 'Use of vehicle restraint systems' for examples.

Parameter: Lane closure mechanism
Options: None; IPV; Tapers; Both

The user should select the method used to close lanes in the works transition zone.

- *IPV*: the lane is closed solely by using an impact protection vehicle; this vehicle is likely to be fitted with an impact attenuator
- *Taper*: the lane is closed solely by a lightweight taper formed using the delineation devices listed above (with or without flashing lights).
- *Both*: the lane is closed by a cone taper, but an IPV within the closed lane provides additional protection to the workforce

Figure 21: Lanes closed by cone tapers or panels (left, middle) and Impact Protection Vehicle (right)

Parameter: Use of vehicle restraint systems

Options: None; Low performance; High performance

Note: This parameter is not relevant for mobile works and will be disabled.

A Vehicle Restraint system (VRS) is a system intended to prevent a vehicle from entering the work zone. If a VRS is used (either temporarily or is permanent infrastructure at the works site) to physically separate the traffic and the work zone then the user should make a judgment as to whether it is low or high performance.

'QMB:' moveable concrete sections

Varioguard ® steel barrier

Miniguard ® steel barrier on the left & fixed New jersey on the right

Temporary concrete barrier

Figure 22: Examples of temporary VMS

The performance level of a VRS is defined following the EN 1317 standards. The selection of the more appropriate VRS is usually based on impact likeliness, vehicles types and road / work zone geometry. The Designer shall agree the provision of safety barriers with the National Roads Authority, not only the containment level, but also the working width and the permitted ASI (Acceleration Severity Index). When selecting the VRS characteristics, the designer should also consider that higher containment level barriers are stiffer and less forgiving and shall be used only when the hazard that needs to be mitigated would be greater than that due to the impact with the barrier. As working widths are very much site specific, the maximum working width permissible will be determined on a site-by-site basis.

For the purpose of the STARs evaluation tool, it is proposed that the barrier shall have at least the N2 containment Level to be classified as “High performance VRS”. The N2 containment level is commonly used for temporary safety barrier in work zones. To gain this containment level, VRS must pass both the TB11[3] and TB32[4] impact tests.

Any VRS complying to a lower containment level (understand a lower impact energy) should be considered as a “Low performance VRS” in the STARs evaluation tool.

Parameter: Use of lookout systems

Options: None; Manual; Automatic

A manual lookout system is when a worker has the specific task of acting as lookout to provide warning. An automatic lookout system is when the same task is carried out automatically. The user should select whichever option is most relevant.

Figure 23: (Left) Road worker on left acting as 'look out' for worker placing cones and (right) 'Intellicone' automatic warning system

Parameter: Use of physical traffic management

Options: None; Rumble strips; Narrow lanes with channelizing devices; Transverse pavement marking; Other

Note: This parameter is not relevant for mobile works

The user should select as appropriate if any physical traffic management techniques are used. Options are:

- Rumble strips: Strips on the road that cause a vibration and audible rumbling through the wheels into the car body and therefore alert the driver to potential dangers
- Narrow lanes with channelizing devices: cones, cylinders, panels and barriers
- Transverse pavement marking: painted markings across the road surface intended to encourage drivers to reduce speed.
- Other: any other technique that would be categorised as physical traffic management e.g. ‘speed bumps‘ laid on the road surface

Parameter: Use of TMA/LMCC

Options: None; 1; More than 1

TMA is the abbreviation of Truck Mounted Attenuator; LMCC is the abbreviation of Lorry-Mounted Crash Cushion.

[3] The TB11 test is realised with 900 kg car impacting the VRS at 100 km/h with a 20°impact angle.

[4] The TB32 test is realised with 1500 kg car impacting the VRS at 110 km/h with a 20°impact angle.

Figure 24: Vehicle fitted with an LMCC

Parameter: Control through carriageway design
Options: Yes; No
Note: This parameter is not relevant for mobile works.

The user should select ”Yes” if the road surface or carriageway design is used to control traffic through the roadworks. Examples of this could be temporary road markings, road studs etc. which identify the path drivers are required to take.

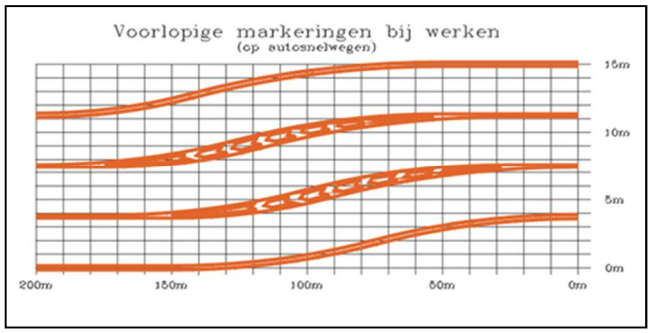


Figure 25: Neutral area is used between lanes when 2 (or more) adjacent lanes must be deviated (Source: Flanders regulations)

Parameter: Width of open lane 1
Options: 2.5; 3; 3.25; 3.5; Greater than 3.5
Note: This parameter is not relevant for mobile works and will be disabled.

Parameter: Width of open lane 2
Options: 2.5; 3; 3.25; 3.5; Greater than 3.5; N/A
Note: This parameter is not relevant for mobile works and will be disabled.

Parameter: Width of open lane 3
Options: 2.5; 3; 3.25; 3.5; Greater than 3.5; N/A
Note: This parameter is not relevant for mobile works and will be disabled.

The user should select the option closest to the width of each open lane. Most countries publish guidelines or codes of practice for temporary traffic management and these should provide the minimum lane widths. There are generally lane widths that are the very minimum acceptable, recommended minimum and minimum for lanes that will only permit cars. For example, in Ireland, the optimum lane width for all classes of vehicles is 3.25m. This may be reduced to a minimum of 3.0m. Below this, HGVs and buses must be marshalled past the works. The absolute minimum lane width, if only cars and light vehicles are present, is 2.5m.

Parameter: Workforce training

Options: Yes; No

The user should select “Yes” if the workforce is trained, qualified and competent. This may be if there are mandatory national training schemes and qualifications for road workers. If there are qualifications and training available but they are not mandatory, then the user should make a judgement as to whether the workforce is likely to be compliant.

Parameter: Workforce PPE standards

Options: Yes; No

The user should select “Yes” if there is a standard or guidance governing Personal Protective Equipment for the traffic management workforce in the relevant country.

Figure 26: UK road workers wearing jackets to EN471 Class 3 (mandatory when working on high-speed roads) and trousers to EN471 Class 1

Parameter: TM vehicle conspicuity standards

Options: Yes; No

The user should select “Yes” if there is a standard or guidance governing works vehicle conspicuity in the relevant country.

Examples:

The following photo shows a UK vehicle with lights and markings which meet the requirements of the Traffic Signs Manual Chapter 8, Part 2: Operations.

Figure 27: UK works vehicle

In Belgium, the federal decree of May 7th, 1999 concerning the signing of road work activities and other obstructions on public roads and the regional standard tender specifications regulate the vehicle conspicuity standards (see following pictures).

Figure 28: (Left) Works vehicle provided with 45° inclined red and white strips flashing lights, A31 and D1 signs (decree of May 7th, 1999). (Right)The conspicuity of the safety vehicle is regulated by the same decree but the regional standard tender specifications provide additional rules (i.e. must be equipped with a TMA)

Parameter: Works design legislation/standards
Options: Yes; No
The user should select “Yes” if there exists legislation or guidance specifying standard layouts and traffic management solutions for this type of road works, for example in a national road works manual or similar.

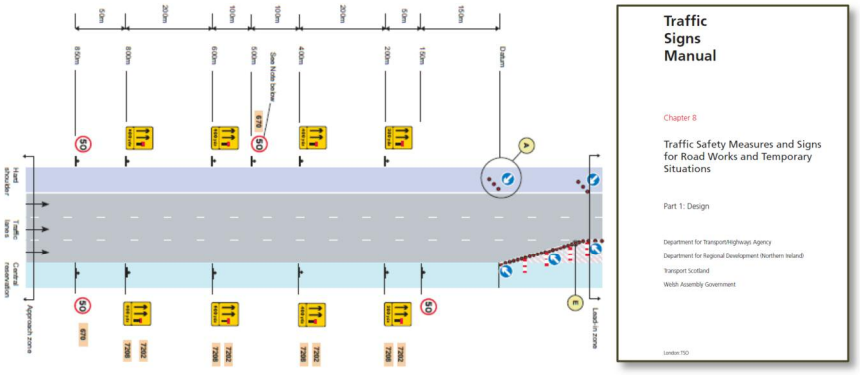


Figure 29: UK requirements are covered in Traffic Signs Manual, Chapter 8 and the Traffic Signs Regulations and General Directions.

Parameter: Safety management system requirements
Options: Yes; No
The user should select “Yes” if there are mandatory requirements on road works associated with the management of safety. These should include having the following in place:

- Nominated personnel with appropriate responsibility
- Safety policies
- Risk assessments
- Control measures for risks identified
- Non-conformities identified and corrected
- Defined communication channels

5 Case studies

Five case studies, representative of five different road work schemes, are presented hereafter to illustrate and discuss the results obtained with the STARs evaluation tool.

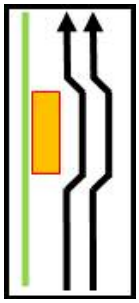
Case 1:

Major RW (40 days long)

2x2 motorway

2 lanes open

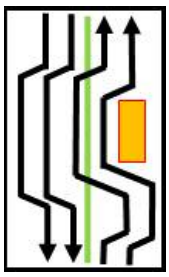
Use of the hardshoulder



Parameter:	**Value** (from the options list):
Base characteristics	
Number of lanes	2x2
Hardshoulder	H/S
Time of day	Continuously
Lighting conditions	Lit (night-time)
Hourly traffic distribution	Standard
Layout characteristics	
Length of whole works	3 to 4 km (regulation advance warning: 2500m; transition area: 150m; activity area: 750m; termination area: 150m)
Type of layout	Lane closure
Number of lanes closed, main direction	1
Number of lanes closed, opposite direction	0
Lane closure location	Fast
Lanes open, in main direction	2
Lanes open in opposite direction	2
Worker characteristics	
Number of workers installing/clearing	Less than 5
Number of workers in closure	5 to 20
Number of workers for maintenance	Less than 5
Number of carriageway crossings	10 to 40
Timing characteristics	
Time taken for installation	1 hour to 10 hours
Time taken for works	7 to 30 days
Time taken for maintenance	1 hour to 10 hours
Time taken for clear away	1 hour to 10 hours
Speed and flow characteristics	
AADT (total flow for both directions)	48000 to 72000 (55.000 veh./d)
Typical hourly flow (carriageway main direction)	3000 veh/hr to 5000 veh/hr (3.300 veh/h)
Free-flow speed in normal conditions	120
Work zone speed limit	70

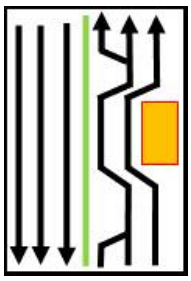
Speed limit units	km/h
Speed compliance management	Variable: Nothing or Vehicle activated signs or Spot enforcement
Traffic HGV composition	More than 20%
Risk mitigation measures	
Far advance warning	Sign (VMS)
Far advance warning, length	2500m (in fact 5000m)
Lateral distance between workzone & traffic	Standard (0,5m)
Signage levels	Optimised (regional regulations)
Delineation	*Variable*: Panels or Temporary barrier
Lane closure mechanism	*Variable*: Tapers or Both
Use of vehicle restraint systems	*Variable*: None or Low performance
Use of lookout systems	None
Use of physical traffic management	*Variable*: None or Transverse pavement marking
Use of TMA/LMCC	*Variable*: None or 1
Control through carriageway design	Yes (road markings)
Width of open lane 1	3.25m
Width of open lane 2	2.5m
Width of open lane 3	N/A
Workforce training	Yes
Workforce PPE standards	Yes
TM vehicle conspicuity standards	Yes
Works design legislation/standards	Yes
Safety management system requirements	Yes

Case 2:

	Parameter:	**Value** (from the options list):
Major RW	Base characteristics	
2x2 motorway	Number of lanes	2x2
Contraflow	Hardshoulder	H/S
2 lanes open	Time of day	Continuously
	Lighting conditions	Variable: Lit (night-time); Unlit (night-time)
	Hourly traffic distribution	Standard
	Layout characteristics	
	Length of whole works	4 to 5 km (regulation advance warning: 2500m; transition area: 150m+300m+150m; activity area: 1200m; termination area: 150m)
	Type of layout	Contraflow
	Number of lanes closed, main direction	1
	Number of lanes closed, opposite direction	0
	Lane closure location	Slow
	Lanes open, in main direction	2
	Lanes open in opposite direction	2
	Worker characteristics	
	Number of workers installing/clearing	Less than 5
	Number of workers in closure	5 to 20
	Number of workers for maintenance	Less than 5
	Number of carriageway crossings	10 to 40
	Timing characteristics	
	Time taken for installation	1 hour to 10 hours
	Time taken for works	30 to 60 days
	Time taken for maintenance	1 hour to 10 hours
	Time taken for clear away	1 hour to 10 hours
	Speed and flow characteristics	
	AADT (total flow for both directions)	48000 to 72000 (55.000 veh./d)
	Typical hourly flow (carriageway main direction)	3000 veh/hr to 5000 veh/hr (3.300 veh/h)
	Free-flow speed in normal conditions	120
	Work zone speed limit	70
	Speed limit units	km/h
	Speed compliance management	Variable: Spot enforcement or Section control
	Traffic HGV composition	More than 20%

Risk mitigation measures	
Far advance warning	Sign (VMS)
Far advance warning, length	2500m (in fact 5000m)
Lateral distance between workzone & traffic	Standard (0,5m)
Signage levels	Optimised (regional regulations)
Delineation	Temporary barrier
Lane closure mechanism	*Variable*: Tapers or Both
Use of vehicle restraint systems	High performance
Use of lookout systems	None
Use of physical traffic management	*Variable*: None or Transverse pavement marking
Use of TMA/LMCC	*Variable*: None or 1
Control through carriageway design	Yes (road markings)
Width of open lane 1	3.25m
Width of open lane 2	2.5m
Width of open lane 3	N/A
Workforce training	Yes
Workforce PPE standards	Yes
TM vehicle conspicuity standards	Yes
Works design legislation/standards	Yes
Safety management system requirements	Yes

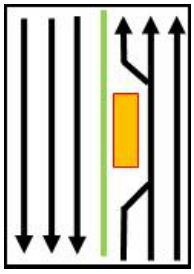
Case 3:

	Parameter:	**Value** (from the options list):
Major RW	Base characteristics	
2x3 motorway	Number of lanes	2x3
Lane closure	Hardshoulder	H/S
2 lanes open	Time of day	Continuously
	Lighting conditions	Lit (night-time)
	Hourly traffic distribution	Standard
	Layout characteristics	
	Length of whole works	4 to 5 km (regulation advance warning: 2500m; transition area: 150m+300m+150m; activity area: 750m; termination area: 150m)
	Type of layout	Lane closure
	Number of lanes closed, main direction	1
	Number of lanes closed, opposite direction	0
	Lane closure location	Slow
	Lanes open, in main direction	2
	Lanes open in opposite direction	3
	Worker characteristics	
	Number of workers installing/clearing	Less than 5
	Number of workers in closure	5 to 20
	Number of workers for maintenance	Less than 5
	Number of carriageway crossings	10 to 40
	Timing characteristics	
	Time taken for installation	1 hour to 10 hours
	Time taken for works	7 to 30 days
	Time taken for maintenance	1 hour to 10 hours
	Time taken for clear away	1 hour to 10 hours
	Speed and flow characteristics	
	AADT (total flow for both directions)	72000 to 96000 (95.000 veh./d)
	Typical hourly flow (carriageway main direction)	More than 5000 veh/hr (5.700 veh/h)
	Free-flow speed in normal conditions	120
	Work zone speed limit	70
	Speed limit units	km/h
	Speed compliance management	Variable: Nothing or Vehicle activated signs or Spot enforcement
	Traffic HGV composition	12 to 20%

Risk mitigation measures	
Far advance warning	Sign (VMS)
Far advance warning, length	2500m (in fact 5000m)
Lateral distance between workzone & traffic	Variable: Standard (0,5m) or Above standard (1,5m)
Signage levels	Optimised (regional regulations)
Delineation	Temporary barrier
Lane closure mechanism	*Variable*: Tapers or Both
Use of vehicle restraint systems	*Variable*: low or High performance
Use of lookout systems	None
Use of physical traffic management	*Variable*: None or Transverse pavement marking
Use of TMA/LMCC	*Variable*: None or 1
Control through carriageway design	Yes (road markings)
Width of open lane 1	Variable: 3.25m or 3.5m
Width of open lane 2	Variable: 2.5m or 3m
Width of open lane 3	N/A
Workforce training	Yes
Workforce PPE standards	Yes
TM vehicle conspicuity standards	Yes
Works design legislation/standards	Yes
Safety management system requirements	Yes

Case 4:

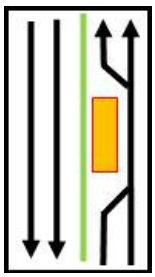
Minor RW
2x3 motorway
Lane closure
2 lanes open



Parameter:	**Value** (from the options list):
Base characteristics	
Number of lanes	2x3
Hardshoulder	H/S
Time of day	Daytime
Lighting conditions	Lit (daytime)
Hourly traffic distribution	Standard
Layout characteristics	
Length of whole works	3 to 4 km (regulation advance warning: 2500m; transition area: 150m; activity area: 1000m; termination area: 150m)
Type of layout	Lane closure
Number of lanes closed, main direction	1
Number of lanes closed, opposite direction	0
Lane closure location	Fast
Lanes open, in main direction	2
Lanes open in opposite direction	3
Worker characteristics	
Number of workers installing/clearing	More than 5
Number of workers in closure	5 to 20
Number of workers for maintenance	Less than 5
Number of carriageway crossings	Less than 10
Timing characteristics	
Time taken for installation	1 hour to 10 hours
Time taken for works	10 to 24 hours
Time taken for maintenance	Less than 1 hour
Time taken for clear away	1 hour to 10 hours
Speed and flow characteristics	
AADT (total flow for both directions)	48000 to 72000 (70.000 veh./d)
Typical hourly flow (carriageway main direction)	3000 to 5000 veh/hr (4.300 veh/h)
Free-flow speed in normal conditions	120
Work zone speed limit	70
Speed limit units	km/h
Speed compliance management	Variable: Nothing or Vehicle activated signs
Traffic HGV composition	7 to 12%

Risk mitigation measures	
Far advance warning	Sign (VMS)
Far advance warning, length	2500m (in fact 3000m)
Lateral distance between workzone & traffic	Standard (0,5m)
Signage levels	Variable: Optimised (regional regulations) or Optimised plus (additional LED VMS)
Delineation	*Variable*: cones or panels
Lane closure mechanism	*Variable*: Tapers or Both (tapers + IPV)
Use of vehicle restraint systems	None
Use of lookout systems	Variable: None or automatic
Use of physical traffic management	None
Use of TMA/LMCC	*Variable*: None or 1
Control through carriageway design	No
Width of open lane 1	Greater than 3.5m
Width of open lane 2	3,5m
Width of open lane 3	N/A
Workforce training	Yes
Workforce PPE standards	Yes
TM vehicle conspicuity standards	Yes
Works design legislation/standards	Yes
Safety management system requirements	Yes

Case 5:

	Parameter:	**Value** (from the options list):
Mobile RW	Base characteristics	
2x2 motorway	Number of lanes	2x2
Lane closure	Hardshoulder	H/S
1 lane open	Time of day	Variable: Night-time; Daytime
	Lighting conditions	Variable: Lit (daytime); Unlit (night-time)
	Hourly traffic distribution	Standard
	Layout characteristics	
	Length of whole works	500m to 1 km (regulation advance warning: 500m; transition area: 100m (safety vehicles included); activity area: 50m (work vehicle included))
	Type of layout	Lane closure
	Number of lanes closed, main direction	1
	Number of lanes closed, opposite direction	0
	Lane closure location	Fast
	Lanes open, in main direction	1
	Lanes open in opposite direction	2
	Worker characteristics	
	Number of workers installing/clearing	Less than 5
	Number of workers in closure	Less than 5
	Number of carriageway crossings	Less than 10
	Timing characteristics	
	Time taken for installation	Less than 1 hour
	Time taken for works	Less than 10 hours
	Time taken for clear away	Less than 1 hour
	Speed and flow characteristics	
	AADT (total flow for both directions)	24000 to 48000 (36.000 veh./d)
	Typical hourly flow (carriageway main direction)	1000 to 3000 veh/hr (2.160 veh/h)
	Free-flow speed in normal conditions	120
	Work zone speed limit	120
	Speed limit units	km/h
	Speed compliance management	Nothing
	Traffic HGV composition	12 to 20%
	Risk mitigation measures	
	Far advance warning	Variable: Nothing or Sign (VMS)
	Far advance warning, length	1000m

Lateral distance between workzone & traffic	Standard (0,5m)
Signage levels	Variable: Optimised (regional regulations) or Optimised plus (additional LED VMS) IPV
Lane closure mechanism	None
Use of lookout systems	*Variable*: 1 or more than 1
Use of TMA/LMCC	Yes
Workforce training	Yes
Workforce PPE standards	Yes
TM vehicle conspicuity standards	Yes
Works design legislation/standards	Yes
Safety management system requirements	

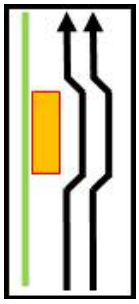
6 Interpreting the results

In this section, we analyse and interpret the results of the five case studies which have been defined in the previous section.

For each case, we define at first the size of the complete set of alternatives and number of dominant alternatives. The dominant alternatives are the alternatives which are the best candidates for the multicriteria analysis (i.e. if an alternative is dominant, there is not another alternative in the set which has a better evaluation for a criterion). Evaluating the number of alternatives and the number of dominant solutions allows us to highlight the multicriteria nature of the problem.

Then we analyse the results of the multicriteria analysis (cf. Section 2 for complementary information about the methodology). From the evaluations of the marginal utility functions, we generate a sorting of the dominant solutions in each STARs class. Then, we identify the best roadwork schemes associated to the case study.

Case 1:

Main characteristics	**Variable parameters**	**Value** (from the options list)
Major RW (40 days long) 2x2 motorway 2 lanes open Use of the hardshoulder 	Speed compliance management Delineation Lane closure mechanism Use of vehicle restraint systems Use of physical traffic management Use of TMA/LMCC	*Nothing* or *Vehicle activated signs* or *Spot enforcement* *Panels* or *Temporary barrier* *Tapers* or *Both* *None* or *Low performance* *None* or *Transverse pavement marking* *None* or *1*

Number of alternatives: **96**

Number of dominant alternatives: **3**

Then, we obtain the following evaluations for the dominant alternatives. Table 5 shows the evaluations on the criteria while Table 6 shows the evaluations on the marginal utility functions (i.e. kind of normed evaluations) with the corresponding STARs classes.

Alternative n°	**Road workers safety [risk]**	**Road users safety [risk per veh]**	**Traffic performance [log(delay)]**
Alt. 62	0.2006	2.75E-5	2.1143
Alt. 64	0.1644	2.18E-5	2.1439
Alt. 96	0.1480	1.94E-5	2.1543

Table 5: Evaluations on the set of criteria

Alternative n°	Utility (RWS)	Utility (RUS)	Utility (TP)	STARs (RWS)	STARs (RUS)	STARs (TP)
Alt. 62	0.6988	0.4210	0.3972	4	3	2
Alt. 64	0.7711	0.4682	0.3971	4	3	2
Alt. 96	0.8027	0.4884	0.3970	5	3	2

Table 6: Evaluations on the marginal utility functions

From the previous table, we observe that Alternative 96 is the best on the criteria RWS and RUS but it performs less well for the criterion TP. However, the utility score of Alternative 93 for the criterion TP is very close to the score of the other dominant solutions. Consequently, if we generate a ranking based on the aggregated utility score of the dominant solutions (with equal weights on each criterion), we observe that **Alternative 96 is ranked in the first position and is located in the STARs class 3**. Table 7 shows the final ranking of the dominant solutions, depending on the aggregated utility score for each dominant solution and the associated STARs class.

Alternative n°	Utility (aggr.)	STARs (aggr.)	Final rank
Alt. 62	0.5057	3	3
Alt. 64	0.5454	3	2
Alt. 96	**0.5627**	**3**	**1**

Table 7: Aggregated score and final rank of the dominant solutions

Alternative 96 has the following values for the variable parameters:

- Speed compliance management: *Spot enforcement (police, spot speed cameras)*
- Delineation: *Temporary barriers*
- Lane closure mechanism: *Both (i.e. IPV and tapers)*
- Use of vehicle restraint systems: *Low performance*
- Use of physical traffic management: *Transverse pavement marking*
- Use of TMA/LMCC: *1*

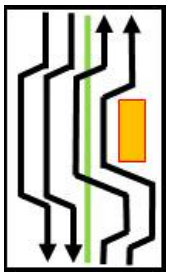
As a comparison, these are the values for the variable parameters of the alternatives 64 (U = 0.5454) and 62 (U = 0.5057) respectively, which are the second and the third best solutions.

- Speed compliance management: *Vehicle activated signs*
- Delineation: *Temporary barriers*
- Lane closure mechanism: *Both (i.e. IPV and tapers)*
- Use of vehicle restraint systems: *Low performance*
- Use of physical traffic management: *Transverse pavement marking*
- Use of TMA/LMCC: *1*

- Speed compliance management: *Vehicle activated signs*
- Delineation: *Temporary barriers*
- Lane closure mechanism: *Both (i.e. IPV and tapers)*
- Use of vehicle restraint systems: *Low performance*
- Use of physical traffic management: *None*
- Use of TMA/LMCC: *1*

From the observation of these values, we can conclude that the use of *Temporary barriers*, the use of *IPV and tapers* as a lane closure mechanism, the use of *Low performance* vehicle restraint systems and the use of *1* TMA/LMCC are very important in this case study to obtain good performing solutions. Then, the values of Alternative 62 seem to indicate that it is possible to obtain a good solution without any use of physical traffic management. Moreover, both *Spot enforcement* and *Vehicle activated signs* are good solutions for the speed compliance management.

Case 2:

Main characteristics	**Variable parameters**	**Value** (from the options list)
Major RW 2x2 motorway Contraflow 2 lanes open 	Lighting conditions	*Lit (night-time)* or *Unlit (night-time)*
	Speed compliance management	*Spot enforcement* or *Section control*
	Lane closure mechanism	*Tapers* or *Both*
	Use of physical traffic management	*None* or *Transverse pavement marking*
	Use of TMA/LMCC	*None* or *1*

Number of alternatives: **32**

Number of dominant alternatives: **1**

Then, we obtain the following evaluations for the dominant alternative. Table 8 shows the evaluations on the criteria while Table 9 shows the evaluations on the marginal utility functions with the corresponding STARs classes.

Alternative n°	**Road workers safety [risk]**	**Road users safety [risk per veh]**	**Traffic performance [log(delay)]**
Alt. 8	0.1386	7.31E-7	9.1835

Table 8: Evaluations on the set of criteria

Alternative n°	**Utility (RWS)**	**Utility (RUS)**	**Utility (TP)**	**STARs (RWS)**	**STARs (RUS)**	**STARs (TP)**
Alt. 8	0.8152	1	0.3778	5	5	2

Table 9: Evaluations on the marginal utility functions

Table 10 shows that Alternative 8 obtains an aggregated utility score of 0.7310 which corresponds to a STARs class of 4.

Alternative n°	Utility (aggr.)	STARs (aggr.)	Final rank
Alt. 8	0.7310	4	1

Table 10: Aggregated score and final rank of the dominant solution

Alternative 8 has the following values for the variable parameters:

- Lighting conditions: *Lit (night time)*
- Speed compliance management: *Spot enforcement (police, spot speed cameras)*
- Lane closure mechanism: *Both (i.e. IPV and tapers)*
- Use of physical traffic management: *Transverse pavement marking*
- Use of TMA/LMCC: *1*

As a comparison, these are the characteristics of the three best dominated solutions. In other words, these are the alternatives which are dominated by Alternative 8 but which obtain the best aggregated utility score.

Alternative 16 – best dominated solution (U = 0.7309; STARs class 4)

- Lighting conditions: *Lit (night time)*
- Speed compliance management: *Continuous enforcement*
- Lane closure mechanism: *Both (i.e. IPV and tapers)*
- Use of physical traffic management: *Transverse pavement marking*
- Use of TMA/LMCC: *1*

Alternative 4 – second best dominated solution (U = 0.7162; STARs class 4)

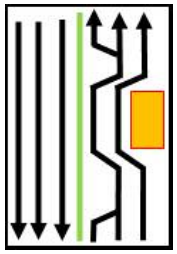
- Lighting conditions: *Lit (night time)*
- Speed compliance management: *Spot enforcement (police, spot speed cameras)*
- Lane closure mechanism: *Tapers*
- Use of physical traffic management: *Transverse pavement marking*
- Use of TMA/LMCC: *1*

Alternative 12 – third best dominated solution (U = 0.7162; STARs class 4)

- Lighting conditions: *Lit (night time)*
- Speed compliance management: *Continuous enforcement*
- Lane closure mechanism: *Tapers*
- Use of physical traffic management: *Transverse pavement marking*
- Use of TMA/LMCC: *1*

As a consequence of the observation of these values, we can conclude that for this specific case study, the *Lit (night time)* condition, the use of *Transverse pavement making* for the physical traffic management and the use of *1* TMA/LMCC are strongly associated with a good performing alternative. Then, the use of *Tapers and IPV* rather than *Tapers only* seems quite important. And finally, speed compliance management appears to be the parameter with the (relative) lowest impact on the final result of the best alternatives.

Case 3:

Main characteristics	**Variable parameters**	**Value** (from the options list)
Major RW 2x3 motorway Lane closure 2 lanes open 	Speed compliance management	*Nothing* or *Vehicle activated signs* or *Spot enforcement*
	Lateral distance between workzone & traffic	*Standard (0,5m)* or *Above standard (1,5m)*
	Lane closure mechanism	*Tapers* or *Both*
	Use of vehicle restraint systems	*Low* or *High performance*
	Use of physical traffic management	*None* or *Transverse pavement marking*
	Use of TMA/LMCC	*None* or *1*
	Width of open lane 1	*3.25m* or *3.5m*
	Width of open lane 2	*2.5m* or *3m*

Number of alternatives: **384**

Number of dominant alternatives: **3**

Then, we obtain the following evaluations for the dominant alternatives. Table 11 shows the evaluations on the criteria while Table 12 shows the evaluations on the marginal utility functions (i.e. kind of *normed* evaluations) with the corresponding STARs classes.

Alternative n°	**Road workers safety [risk]**	**Road users safety [risk per veh]**	**Traffic performance [log(delay)]**
Alt. 248	0.1667	1.67E-5	9.7728
Alt. 256	0.1305	1.39E-5	9.8227
Alt. 384	0.1175	1.21E-5	9.8357

Table 11: Evaluations on the set of criteria

Alternative n°	**Utility (RWS)**	**Utility (RUS)**	**Utility (TP)**	**STARs (RWS)**	**STARs (RUS)**	**STARs (TP)**
Alt. 248	0.7666	0.5105	0.3761	4	3	2
Alt. 256	0.8259	0.5346	0.3759	5	3	2
Alt. 384	0.8433	0.5490	0.3728	5	3	2

Table 12: Evaluations on the marginal utility functions

From the previous table, we observe that Alternative 384 obtains the best evaluations on the utility functions of the criteria RWS and RUS while Alternative 248 obtains the best evaluation on the criteria TP. However, if we generate a ranking based on the aggregated utility score of the dominant solutions (with equal weights on each criterion), we observe that **Alternative 384 is ranked at the first position and it is located in the STARs class 3**. Table 13 shows the final rank of the dominant solutions, depending on the aggregated utility score for each dominant solution and the associated STARs class.

Alternative n°	Utility (aggr.)	STARs (aggr.)	Final rank
Alt. 248	0.5511	3	3
Alt. 256	0.5788	3	2
Alt. 384	**0.5894**	**3**	**1**

Table 13: Aggregated score and final rank of the dominant solutions

Alternative 384 has the following values for the variable parameters:

- Speed compliance management: *Spot enforcement (police, spot speed cameras)*
- Lateral distance between workzone & traffic: *Above standard (1,5m)*
- Lane closure mechanism: *Both*
- Use of vehicle restraint systems: *High performance*
- Use of physical traffic management: *Transverse pavement marking*
- Use of TMA/LMCC: *1*
- Width of open lane 1: *3,5m*
- Width of open lane 2: *3m*

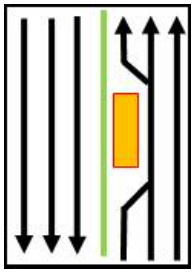
As a comparison, these are the values for the variable parameters of Alternative 256 (U = 0.5788) and Alternative 248 (U = 5511) respectively:

- Speed compliance management: *Vehicle activated signs*
- Lateral distance between workzone & traffic: *Above standard (1,5m)*
- Lane closure mechanism: *Both*
- Use of vehicle restraint systems: *High performance*
- Use of physical traffic management: *Transverse pavement marking*
- Use of TMA/LMCC: *1*
- Width of open lane 1: *3,5m*
- Width of open lane 2: *3m*

- Speed compliance management: *Vehicle activated signs*
- Lateral distance between workzone & traffic: *Above standard (1,5m)*
- Lane closure mechanism: *Both*
- Use of vehicle restraint systems: *High performance*
- Use of physical traffic management: *None*
- Use of TMA/LMCC: *1*
- Width of open lane 1: *3,5m*
- Width of open lane 2: *3m*

The analysis of these values shows us that the largest width for the open lanes, the largest lateral distance between workzone and traffic, the use of high performance vehicle restraint systems, the use of IPV and tapers as lane closure mechanism and the use of 1 TMA/LMCC are redundant characteristics of the best solutions. However, the values of Alternative 248 indicate that the use of physical traffic management is less important.

Case 4:

Main characteristics	**Variable parameters**	**Value** (from the options list)
Minor RW 2x3 motorway Lane closure 2 lanes open 	Speed compliance management Signage levels Delineation Lane closure mechanism Use of lookout systems Use of TMA/LMCC	*Nothing* or *Vehicle activated signs* *Optimised (regional regulations)* or *Optimised plus (LED VMS)* *Cones* or *Panels* *Tapers* or *Both* *None* or *Automatic* *None* or *1*

Number of alternatives: **64**

Number of dominant alternatives: **1**

Then, we obtain the following evaluations for the dominant alternatives. Table 14 shows the evaluations on the criteria while Table 15 shows the evaluations on the marginal utility functions with the corresponding STARs classes.

Alternative n°	**Road workers safety [risk]**	**Road users safety [risk per veh]**	**Traffic performance [log(delay)]**
Alt. 64	0.1584	1.51E-5	0.0451

Table 14: Evaluations on the set of criteria

Alternative n°	**Utility (RWS)**	**Utility (RUS)**	**Utility (TP)**	**STARs (RWS)**	**STARs (RUS)**	**STARs (TP)**
Alt. 64	0.7832	0.5241	0.5971	4	3	3

Table 15: Evaluations on the marginal utility functions

From the previous table, we observe that the alternatives 56 and 64 obtain the same evaluation on every criterion. Consequently, these solutions obtain the same values on the marginal utility functions. This means that alternatives 56 and 64 are equivalent with regard to road users' safety, road workers safety and traffic performance. Table 16 shows that these solutions obtain an aggregated utility score of 0.6326 which corresponds to a STARs class of 4.

Alternative n°	**Utility (aggr.)**	**STARs (aggr.)**	**Final rank**
Alt. 64	0.6348	4	1

Table 16: Aggregated score and final rank of the dominant solutions

Alternative 64 has the following values for the variable parameters:

- Speed compliance management: *Vehicle activated signs*
- Signage levels: *Optimised plus*
- Delineation: *Panels*
- Lane closure mechanism: *Both (IPV and Tapers)*
- Use of lookout systems: *Automatic*
- Use of TMA/LMCC: *1*

As a comparison, the following values are the values of variable parameters of the two best dominated solutions. The analysis of these values shows us that there is an important difference from the choice of *Panels* rather than *Cones* for a good-performing roadwork scheme for this case study.

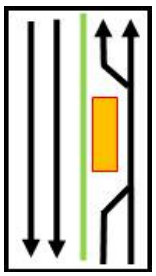
Alternative 56 (U = 0.6301 – STARs class 4) has the following values for the variable parameters:

- Speed compliance management: *Vehicle activated signs*
- Signage levels: *Optimised plus*
- Delineation: *Cones*
- Lane closure mechanism: *Both (IPV and Tapers)*
- Use of lookout systems: *Automatic*
- Use of TMA/LMCC: *1*

Alternative 48 (U = 0.6154 – STARs class 4) has the following values for the variable parameters:

- Speed compliance management: *Vehicle activated signs*
- Signage levels: *Optimised*
- Delineation: *Panels*
- Lane closure mechanism: *Both (IPV and Tapers)*
- Use of lookout systems: *Automatic*
- Use of TMA/LMCC: *1*

Case 5:

Main characteristics		**Variable parameters**	**Value** (from the options list)
Mobile RW 2x2 motorway Lane closure 1 lane open		Time of day Lighting conditions Far advance warning Signage levels Use of TMA/LMCC	*Night-time* or *Daytime* *Lit (daytime)* or *Unlit (night-time)* *Nothing* or *Sign (VMS)* *Optimised (regional regulations)* or *Optimised plus (LED VMS)* *1* or *More than 1*

Number of alternatives: **32**

Number of dominant alternatives: **1**

Then, we obtain the following evaluations for the dominant alternatives. Table 17 shows the

evaluations on the criteria while Table 18 shows the evaluations on the marginal utility functions with the corresponding STARs classes.

Alternative n°	Road workers safety [risk]	Road users safety [risk per veh]	Traffic performance [log(delay)]
Alt. 8	0.4666	1.35E-5	1E-7

Table 17: Evaluations on the set of criteria

Alternative n°	Utility (RWS)	Utility (RUS)	Utility (TP)	STARs (RWS)	STARs (RUS)	STARs (TP)
Alt. 8	0.4762	0.5406	1	3	3	5

Table 18: Evaluations on the marginal utility functions

Table 19 shows that Alternative 8 obtains an aggregated utility score of 0.6723 which corresponds to a STARs class of 4.

Alternative n°	Utility (aggr.)	STARs (aggr.)	Final rank
Alt. 8	0.6723	4	1

Table 19: Aggregated score and final rank of the dominant solutions

Alternative 8 has the following values for the variable parameters:

- Time of day: *Night time*
- Lighting conditions: *Lit*
- Far advance warning: *VMS*
- Signage levels: *Optimised plus*
- Use of TMA/LMCC: *More than 1*

As a comparison, these are the characteristics of the three best dominated solutions. In other words, these are the alternatives which are dominated by Alternative 8 but which obtain the best aggregated utility score.

Alternative 7 – best dominated solution (U = 0.6642; STARs class 4)

- Time of day: *Night time*
- Lighting conditions: *Lit*
- Far advance warning: *VMS*
- Signage levels: *Optimised plus*
- Use of TMA/LMCC: *1*

Alternative 4 – second best dominated solution (U = 0.6632; STARs class 4)

- Time of day: *Night time*
- Lighting conditions: *Lit*
- Far advance warning: *None*
- Signage levels: *Optimised plus*

- Use of TMA/LMCC: *More than 1*

Alternative 6 – third best dominated solution (U = 0.6600; STARs class 4)

- Time of day: *Night time*
- Lighting conditions: *Lit*
- Far advance warning: *VMS*
- Signage levels: *Optimised*
- Use of TMA/LMCC: *More than 1*

As a consequence of the observation of these values, we can conclude that for this specific case study, the *Lit* condition during *Night time* is strongly associated to a good performing alternative. Moreover, we observe that it is (logically) important to prefer an *Optimised plus* signage level rather than an *Optimised*.